PERFORMANCE EFFECTS OF ONE NIGHT'S SLEEP DEPRIVATION

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ABSTRACT

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As modern technology continues to advance and as industry becomes increasingly reliant upon around-the-clock operations, the study of sleep loss has become extremely important. In general, an examination of performance effects following one night's sleep deprivation on various information processing resources (e.g., perceptual, central processing, and motor output) has revealed ambiguous results; in some cases performance decrements are found and in other cases performance remains unaffected. In the present study it was argued that some of the ambiguity in previous research can be attributed to a lack of standardization in the tests that were employed, and a variety of methodological problems. It was hypothesized that the effects of one night's sleep loss on various information processing resources would be more effectively examined using a standardized test battery called the NATO/AGARD Standardized Tests for Research and Environmental Stressors (STRES) Battery.

The present study had eleven male subjects perform the STRES Battery, which is comprised of seven tests (Reaction Time, Memory Search, Mathematical Processing, Spatial Processing, Grammatical Reasoning, Unstable Tracking, and Dual-Task) after four rested testing sessions and two sleep loss sessions (18 hours and 24 hours), over a period

of five days. The effects of one night's (24 hours) sleep loss on the perceptual resource (Reaction Time Tests) indicated erratic and unpredictable fluctuations in response speed, often without any overall increases in response time. There were also strong indications that increased probabilities in error can result. The sleep loss effects on the central processing resource indicated that performance degradations may or may not occur depending on the degree to which working memory is aroused by a particular test. It was found that the very difficult test (Grammatical Reasoning) and very easy test (Memory Search) resulted in poorest overall performance, while the moderately demanding Spatial and Mathematical Processing Tests fared much better following sleep loss. Lastly, the effects of sleep loss on the Unstable Tracking Test demonstrated that the maintenance of stable and accurate motor performance is impaired after only one night without sleep.

Several implications for the design of person-machine systems and jobs can be drawn from the results of the current study. The results demonstrated that performance on each information processing resource, that is, perception, central processing (cognition/decision making), and motor output, are affected to a certain extent by only one night without sleep.

CHAPTER I

INTRODUCTION

As modern technology continues to advance and as industry becomes increasingly reliant upon around-the-clock operations, the effect of sleep - or more precisely, the lack of sleep - has become a study of special interest. This interest poses many important questions and concerns about human operator performance under low levels of sleep, and perhaps reduced levels of alertness. The operational consequences associated with sleep loss are evident in many settings.

Sleep loss in commercial and military aviation has become commonplace (Hawkins, 1978; Green, 1984; Farmer and Green, 1985). Graeber (1989) indicated that reduced alertness and sleepiness during long-haul transmeridian flights can result from the accumulation of sleep loss that evolves from the inability to sleep while traveling through multiple time zones. Graeber (1988) also demonstrated the detrimental effects of sleep loss that can develop during short-haul flights. Similarly, long-haul truck drivers sometimes fall asleep at the wheel (Mackie and Miller, 1978; Moore-Ede, 1993). Many long-haul truckers avoid commuter rush hours by traveling throughout the night and early morning hours, often covering over 4,000 miles per week.

The effects of one or more nights of total sleep loss has been found to significantly impair human activities in "continuous operations", or CONOPS, and "sustained operations", or SUSOPS (Krueger, 1989). CONOPS involve situations in which humans perform their regularly assigned tasks during an entire period without sleep. Examples of CONOPS include international financial/investment centers, police, fire and ambulatory services, telecommunication networks, and chemical process and energy production plants, to name a few. The disastrous accidents at the Chernobyl nuclear power plant in the Commonwealth of Independent States and the Three Mile Island nuclear facility in Pennsylvania, are examples of human error that occurred during early morning (i.e., between 0100 and 0400) operations, when humans would normally be sleeping. SUSOPS are typically unplanned events and continue until the task objective(s) is(are) completed. Generally, SUSOPS are long enough to develop fatigue and cognitive impairment. Examples of SUSOPS include large-scale emergency medical operations, forest fire fighting, combat and military operations and medical internships and residentships. For a medical intern or resident, an average workday can typically keep one continuously "awake" for up to 36 hours. SUSOPS also includes various combat and military operations (Haslam and Abraham, 1987; May and Kline, 1987). With the development of night vision systems and other advanced night-combat equipment, around-the-clock combat operations are no longer constrained by lack of technology, but instead may be constrained by human physical and cognitive limitations.

A Brief History of Sleep Deprivation Research

The psychological stress associated with sleep loss has definite effects on human performance. Research into total sleep deprivation has had a relatively long history. In 1896, Patrick and Gilbert were the first to conduct a total sleep deprivation experiment on humans. Three male subjects were kept awake for 88 to 90 hours, during which time physiological and psychological tests were administered, including reaction time, discrimination-time, addition of figures, motor ability, and memory for nonsense syllables.

In general, they found small, but consistent decreases in sensory acuity, response speed, motor speed, and memory ability.

It took another 26 years before a similar experiment was performed. Robinson and Herrmann (1922) examined the effects of 60 to 65 hours of sleep deprivation on three men. They subjected these men to a variety of performance tests including steadiness, accuracy of aiming, muscular strength, letter-naming ability, and mental arithmetic. The performance results were not degraded in any consistent manner due to a lack of sleep, except in mental multiplication. Robinson and Richardson-Robinson (1922) also found no difference in performance between an experimental group of students who were kept awake for 28 hours, compared to a control group who had normal sleep. The authors explained this unpredicted effect as the result of a compensatory effort by the sleep-deprived subjects to reduce the sleep deficit that was probably present.

It seems quite natural to think that performance should vary significantly depending on the amount of sleep deprivation imposed on a human. In fact, after these initial studies, significant performance impairments were discovered and began to be frequently cited in the literature. The chronological history of sleep deprivation research has been reviewed and analyzed by many authors (Kleitman, 1963; Wilkinson, 1965; Johnson, 1982). For purposes of this report, sleep deprivation research can be divided into two broad categories: more than one night's sleep loss (i.e., 34 hours or more), and one night's sleep loss (i.e., between 24 and 34 hours). The former category can be further divided into sleep deprivation over 100 hours, and sleep deprivation between 34 and 100 hours.

Research aimed at the effects of sleep deprivation over 100 hours has typically resulted in significant performance decrements, as would be expected. Katz and Landis (1935) reported the loss of 231 hours of sleep for one subject occurred without physical injury to health. The results indicated that with increasing loss of sleep, delusions, irritability, and a noticeable lack of attention and inability to perform mental operations increased. Edwards (1941) examined auditory reaction time and memory along with some other objective and clinical tests during a 100-hour period without sleep. Reaction time differences between the experimental and control groups were not statistically significant; however, extreme amounts of effort were required by the experimental subjects to keep awake. The auditory signals needed to be loud and continuous, and the subjects nearly fell asleep on numerous occasions. No significant results were found for the memory test with less than 72 hours without sleep. However, performance was significantly impaired after 72 hours for 6 subjects, and even more so after 96 hours for 12 subjects. Pasnau, Naitoh, Stier and Kollar (1968) intensively studied the psychological effects of 205 hours of sleep deprivation on four men. A number of psychological tests were employed including similarities and logical puzzles tests, a short term memory test, an interaction test, and a compensatory tracking task. During the first four days there was a general deterioration in tracking performance, however during the fifth and sixth days a marked increase in errors developed. Performance on the tracking tasks, and the other tests became much worse as the length of sleep loss increased.

A large percentage of the research examined the effects of 34 to 100 hours of sleep loss. Several review articles have been published summarizing research at this level of sleep loss (Kleitman, 1963; Wilkinson, 1965; Johnson and Naitoh, 1974; Johnson, 1982; Hockey 1986; Hockey, 1986). Generally, this research has also found rather strong detrimental effects on a number of psychological tests. A classic study by Williams, Lubin and Goodnow (1959) revealed a marked increase in reaction time, which became stronger as the length of sleep loss increased from 34 to 78 hours. In the same study, after only 48 hours, the number of sums attempted in an addition task decreased significantly. Visual, auditory, and cutaneous vigilance showed significant increases in errors of omission (misses) and errors of commission (false alarms) after only 34 hours of sleep loss. Using a memory task, the authors found dramatic delayed and immediate recall impairments after 51 hours of sleep loss.

The other large portion of research examines the effects of one night's sleep loss (between 24 and 34 hours). Contrary to the effects of more than one night's sleep loss, the performance effects after a night of deprived sleep is rather ambiguous. Once again, the same review articles mentioned above have summarized research at this level of sleep loss (Kleitman, 1963; Wilkinson, 1965; Johnson and Naitoh, 1974; Johnson, 1982; Hockey 1986; Hockey, 1986). Later in this report, detailed descriptions and analyses of many 24-hour sleep loss studies will be given. As the reader will become aware, some research indicates that one night's sleep loss does not significantly impair certain aspects of performance, whereas other research indicates significant performance decrements. The remainder of this introduction will present a framework for examining sleep deprivation research, summarize the contrasting research findings after one night's sleep loss, provide possible reasons for the ambiguity, and propose a standardized test battery to study the true effects of one night's sleep loss.

Framework for Review of Previous Research

To examine the enormous amount of literature pertaining to the loss of one night's sleep, an accepted classificatory scheme will be used to provide a general framework. Sleep deprivation research can be described in terms of any of several current information processing theories (e.g., Sanders, 1983; Wickens, 1984; AGARD AMP Working Group 12, 1989). According to these theories, human performance is dependent on a number of information processing stages and resources. It is hypothesized that there are three primary stages of information processing: perceptual input (perception), central processing (decision), and motor output (action).

Sleep deprivation research relevant to each of the three primary information processing stages will be reviewed consecutively. Research was classified into each category on the basis of the test(s) employed in each experiment. For example, simple and choice reaction time and vigilance tests draw energy from the perceptual resources. Memory, mathematical processing, spatial processing, and grammatical/logical reasoning tasks draw upon central processing resources. Tracking tasks demand motor output resources. Although few attempts have been made to provide a general framework for sleep deprivation research, the author will demonstrate how these information processing stages can serve as an effective guide for analysis.

Studies Relevant to Perceptual Resources

As noted above, this section will examine reaction time and vigilance research following one night's sleep loss. As the studies are reviewed, the reader should pay particular attention to the ambiguous results that are reported across different experiments, and the heterogeneity among the types of tests employed within and between different experiments.

Auditory Vigilance Tasks

The first set of studies examined the effects of sleep deprivation using auditory vigilance tasks. Deaton, Tobias and Wilkinson (1971) sleep deprived 12 men for 33 hours, during which time, performance was measured using the Wilkinson auditory vigilance task. During the 30-min test, subjects heard 500 msec tones every 2 sec against a moderate white noise background. Subjects were instructed to detect tones which were slightly shorter (450 sec) than the rest. The signals occurred randomly, but frequently (i.e., on average, one out of every four tones was a "target signal"). Subjects responded by quickly depressing a key. Results showed a significant decrease in the percentage of correct detections under sleep deprivation. There also was a significant decrease in *d'*, the theory of signal detectability (TSD) sensitivity measure, as a result of sleep deprivation. However, ß, the TSD criterion level, was not significantly affected by the loss of sleep. Glenville, Broughton, Wing and Wilkinson (1978) used a slightly different version of the Wilkinson auditory vigilance task in the study of one night's sleep deprivation. In this experiment, the length of the vigilance task was increased to one hour, and the target signals were slighter shorter (400 msec) than in the previous experiment. Sensitivity, or *d'*, was significantly degraded, along with a significant decrease in the number of hits. Once again, the criterion level, or ß, showed no significant impairments.

Lisper and Kjellberg (1972) subjected eight students to a 30-min auditory reaction time task after they had remained awake for 24 hours. The students were instructed to press a microswitch, held in the preferred hand, as soon as they heard the auditory signal. The signal was a 1000-Hz tone, with a mean interstimulus interval of 3.75 sec. Eleven intervals were randomized over three ten-min periods. There was a significant impairment of response speed after sleep deprivation; however, the decrement was not significant when the same analysis was performed on the first 5 min of the test. Therefore, significance was dependent on time-on-task.

Reaction Time Tasks

Analyses of reaction time and vigilance tasks allow researchers to test the separate stages that constitute the reaction process. Sternberg (1969) introduced the Additive Factor

Method, which proposed that stimulus processing stages can be identified by examining the relation between different task variables. Five stages were identified, which included: a) stimulus encoding, b) response choice, c) motor programming, d) motor activation, and e) response execution. Many of these stages have been examined in sleep deprivation experiments using reaction time and vigilance tasks. Generally speaking, the results are rather ambiguous after one night's sleep deprivation. This may be due to the large variety of reaction time and vigilance tests - specifically, the use of unvalidated tests - that have been employed in pursuit of the underlying perceptual effects.

Following one night's sleep loss, Frowein, Reitsma and Aquarius (1981), examined the performance effects on a visual two-choice reaction time task with 32 male subjects. In addition to sleep loss, the experiment included a drug treatment, where the subject either received an amphetamine derivative or a placebo. The task, adapted from Fitts and Peterson (1964), had the subject seated at a angled desk with a stylus resting at a starting plate. A red warning light was positioned just above the starting plate, and two white reaction lights were mounted on either side of the starting plate. The subject was requested to fixate on the red warning light, and to touch one of the two reaction lights when it was activated. Reaction time (RT) and movement time (MT) data were recorded. RT was defined as the interval between the onset of the reaction light and the release from the starting plate. MT was the interval between the release of the starting plate and the touching of the target plate. Sleep deprivation did not significantly degrade RT; however, further analysis showed that under the placebo condition only, there was a significant decrease in response speed on RT after sleep loss. Decrements in RT were suppressed when the amphetamine was administered. There was no impairment of MT without the placebo, but when the placebo was provided, MT was significantly degraded. There was no significant effect of sleep loss on the percentage of movement errors (i.e., undershoots and overshoots). Both the speed and accuracy of the movements were improved the administration of the amphetamine.

The performance on four choice reaction time test was examined after one night's sleep loss (Glenville, Broughton, Wing and Wilkinson, 1978). A portable cassette recording device presented eight male subjects with a self-paced serial choice reaction time task comprised of four lights arranged in a square with four spatially compatible keys below. When a light turned on, the subject was instructed to press the corresponding key. The test continued for 10 min. Results indicated a significant increase in the mean reaction time and number of gaps, or "lapses" (i.e., when subjects responded after a 1-sec or more latency), after sleep deprivation. However, there was no significant effect on the percentage of errors.

The effects of a single night's sleep loss on the reaction process was examined in a two part experiment by Sanders, Wijnen and van Arkel (1982). The first experiment tested the effects of signal degradation and S-R compatibility on another four-choice reaction test after sleep deprivation. Sixteen males subjects participated in the study. The task was a discrete four-choice reaction test, comprised of a 200 msec visual warning signal, a 800 msec preparatory period, a 500 msec signal, followed by a 4500 msec interstimulus interval. The session lasted 20 min. The signal consisted of a digit composed of a pattern of circular dots. In the signal-degradation condition, some of the dots were eliminated from the digit pattern, and were randomly distributed within the presentation frame. In the S-R compatibility condition, compatibility occurred when the digits were vocally named, whereas a transformed vocal response was required in the incompatible conditions. Reaction time was defined as the length of time between the signal onset and the activation of the microphone by a vocal response. Statistical analysis revealed a significant impairment in mean RT following sleep deprivation. In addition, there was a significant interaction between sleep loss, stimulus degradation, and time-of-test (morning vs. afternoon). There was a stronger effect of sleep deprivation on reaction time to degraded signals, which was impaired to a greater extent in the afternoon than in the morning. In addition, there was a significant increase in the percentage of missed trials and percentage of errors following sleep loss.

In the second part of the experiment, Sanders, Wijnen and van Arken (1982) tested the effects of signal intensity and signal modality on a simple reaction test after sleep deprivation. They enlisted 12 subjects to participate in this study. The simple reaction test consisted of half auditory and half visual signals, with equiprobable interstimulus intervals of 6, 9, 12, 15, 18, 21, and 24 sec. Each session lasted 31.5 min. The auditory signal was a 100-Hz tone, which lasted 500 msec with an intensity of either 35 or 85 dB. The visual signal lasted 500 msec with an intensity of either 55 cd/m^2 or 0.43 cd/m^2. Subjects were seated at a desk and were instructed to press the reaction key as soon as either stimuli was perceived. RT was the length of time between the onset of the stimulus and the activation of the response key. Again, mean RT was impaired after sleep loss; however, sleep loss did not significantly interact with any of the other variables (e.g., intensity and modality).

Wilkinson (1959) tested 12 subjects after 30 hours of sleep loss on the Five Choice test. The test apparatus was designed so the subject was seated in front of a 18-in square, horizontal board. Set within this board were five, 1.5-in diameter discs and lightbulbs, each of which were placed at the angles of a pentagon. The subjects were instructed to tap the disc with a stylus when a bulb was activated. After the disc was touched, another bulb would light until it was touched, and so on. If a disc was incorrectly touched, the task proceeded normally, and the mistake was recorded as an error. The subjects were asked to touch the discs as quickly and accurately as possible. This task continued for 25 min. An additional variable was incorporated: a) subjects were given a 30-sec rest pause after every 5-min period, or b) subjects worked continuously. Results showed a large difference between the sleep deprived and the rested conditions, that is, there was an increase in gaps, or lapses (when subjects responded after a 1.5-sec or longer latency), and a decrease in the number of correct responses. However, these effects were much smaller during the initial part of the test, indicating an interaction with time-on-task. The effect of the rest pauses interacted with the effect of sleep loss, and therefore constrained the generalizability of this study.

The Five Choice test was used again by Wilkinson (1961) in a study with 12 men after one night's sleep deprivation. However, each testing period lasted 30 min (5 min longer than the previous study) in this experiment. Results revealed a significant increase in the number of lapses, and reduction in the number of correct responses after sleep loss. Although the number of errors increased after sleep loss, this effect failed to meet significance.

Using a serial reaction time task, adapted from Leonard (1959), Farmer and Green (1985) presented 16 pilots with a stimulus in one of four locations on a monitor, and they were required to press the corresponding key on a four-choice keyboard. After each response, the stimulus would appear in a new, randomly determined location. Subjects were allowed to use four fingers on their dominant hand. Each testing session lasted 25 min. The results led to significant decrements in response time and increased incidences of response gaps following a single night's sleep loss. However, no significant effects occurred for response accuracy.

Steyvers (1987) investigated 32-hour sleep deprivation effects on the perceptual processes with yet another version of a choice reaction task. Sixteen male subjects were seated in front of a slanted table with eight response buttons arranged in a semi-circular pattern. The starting key was positioned in the center of the semi-circle, approximately 15 cm away from the response buttons. Subjects were asked to react as quickly as possible with their right index finger, moving their finger from the starting key to the activated response key. A correct response was defined as pressing the response key with the same label as the action signal (AS). The AS stayed on for 800 msec. The AS was preceded by a warning signal (WS), with a duration of 800 msec. The WS consisted of a arrow, which either pointed to the left side (indicating the AS belonged to a subset of 2, 3, or 4) or to the right side (indicating the AS belonged to a subset of 5, 6, or 7). The WS was presented 4 sec before every AS. The stimuli (AS and WS) in some trials were degraded. Degraded stimuli were created by a random rearrangement of the original pixel pattern, thus maintaining an equal luminance level. The results of the study indicated that sleep deprivation produced significant increases in individual mean RT, mean MT, and arcsine transformed proportions of errors and omissions.

Wilkinson (1960) examined the effects of between 26 to 30 hours sleep loss on a standard vigilance test. The seated subject watched a glass monitor from a distance of 6 ft for the infrequent appearance of a small, lighted spot, which was slightly brighter than the illuminated background. The signal appeared for only 500 msec in any of 8 positions surrounding the center of the monitor. When the subject detected the signal, he/she was instructed to press a key. The test lasted 40 min. Results showed a significant decrease in the number of hits, however, the effect was largely dependent on the extremely poor performance in the latter portion of each testing period, indicating a time-on-task interaction.

Wilkinson (1964), using essentially the same vigilance test, except for a decreased test length of 30 min, examined the effects of 60 hours of sleep loss. He also provided knowledge of results in this study. Although the study tested the effects of 60 hours of sleep loss, he analyzed the performance results after 24 hours of sleep loss as well. No significant effect was found between the control and experimental groups on the number of hits.

During a 64-hour sleep loss study, Williams, Kearney and Lubin (1965), monitored performance on 3 vigilance tasks. The authors analyzed the effects of sleep loss after 31 hours, and these results are therefore relevant. The vigilance test consisted of five lights (red, yellow, green, blue, and white) arranged in a pentagonal pattern on a display. Fifty-two subjects viewed the display from a seated position, and were instructed to press a response key on a microswitch at the onset of the red light only. Eight of the 30 stimuli were red lights. The onset of all other lights were to be ignored. The vigilance task was varied in its predictability to create three tasks: a) a standard task (S), b) a redundant task (R), and c) an uncertain task (U). Each testing session lasted for 10 min. The S task had a fixed sequence with respect to the spacing between signals and the interstimulus intervals. The R task had a fixed sequence with eight red lights appearing altogether in a consecutive fashion. The U task consisted of a completely randomized pattern. Results showed significant increases in the percentage of errors of omission on the R and U tasks; however, the result was not significant on the S task.

It is evident from these experiments that the results are equivocal. Most of the experiments found significant increases in mean RT, mean MT, number of hits/detections (*d'*), and number of lapses - but not in all cases. On the other hand, those same studies and others failed to reach significance on such measures as the number/percentage of errors, movement errors, and number/percentage of omissions. A possible reason for this variability in results may lie in the lack of standardization in testing. Another reason for this ambiguity may lie in the interaction effects frequently found in some of these studies (e.g., time-on-task, rest pauses, drug treatments, knowledge of results).

Studies Relevant to Central Processing Resources

This section, as described before, will examine mathematical processing, memory search, spatial processing, and grammatical reasoning research following one night's sleep loss. Each of the tests used to measure these abilities require the expenditure of central processing resources, or "higher mental processes". According to Eggemeier (1988), the central processing function identifies working memory as the locus of central activity for three processing functions: a) information manipulation or transformation (e.g., mathematical calculation, pattern recognition); b) reasoning activities, which focus on the use of relational rules on information (e.g., logical reasoning, problem solving); and c) planning and scheduling activities (e.g., system supervision).

Once again, as the studies are reviewed, particular attention should be made to the ambiguous results that are found across different experiments, and the enormous variety of tests employed within and between different experiments.

Mathematical Processing Tasks

Mathematical processing tasks (i.e., addition, subtraction, multiplication, and division) are primarily associated with symbolic information manipulations (Eggemeier, 1988). The purpose of most mathematical processing tasks is to place demands upon the processing resources associated with working memory. Specifically, these tasks incorporate long-term memory retrieval, working memory manipulations, and the sequential calculation of mathematical operations.

Loveland and Williams (1963) examined the effects of about 74 hours without sleep on a self-paced adding task. The authors also analyzed the effects of one night's sleep deprivation, and therefore these results are pertinent. Forty Army soldiers were tested on a modified version of the Wells and Ruesch Continuous Additions Test (1945). The actual test was comprised of 4 sheets with 2 columns; each column consisted of 28 single-digit numbers. Subjects were instructed to add successively the pairs of digits down the columns. Subjects were asked to write the sum of each pair in a third column to the right of the second column. The experimenters emphasized accuracy and speed. Subjects had 3 min to complete each trial. Speed of addition for the control group increased, whereas speed for the experimental group, after only one night's sleep loss, significantly decreased, and dropped even more dramatically as sleep deprivation continued. However, addition accuracy did not significantly differ between the two groups throughout the duration of this sleep loss study.

The effect of one and two night's sleep deprivation were examined by Williams and Lubin (1967) on a variety of work-paced (or experimenter-paced) addition tests. Five different work-paced addition tests were used. Forty Army enlisted men were instructed to write down each digit-pair sum on a sheet with three columns of blank spaces. Both speed and accuracy were emphasized by the experimenters. In one of the addition tests, the 2-step 2-sec test, a pair of digits were presented every 2 sec, and the subjects were asked to add '8' to each sum. Presumably, the 2-step 2-sec test was twice as difficult as the other tests. The experimenters hypothesized that if the sleep loss impaired the central processing functions, then the 2-step test should show considerable degradations. Each testing period was 3 min. After one night's sleep loss, the only significant decrease in speed of addition was found for the 2-step test. However, the effect of one night's sleep loss on the percentage of completed additions was not significant - in fact, only a 2% drop was computed for the 2-step test. Sleep deprivation had no significant effect on the accuracy of addition.

Donnell (1969) used the Wilkinson addition test in an effort to assess the effects of 2 nights without sleep (64 hours). The author also analyzed the effects of sleep deprivation after 32 hours for 11 male subjects. The Wilkinson addition test (1958) had subjects add columns of 5 two-digit numbers for 60 min. Subjects were instructed to work as quickly and efficiently as possible. The author measured the number of additions attempted and the percentage correct during each 2-min period. After one night's sleep deprivation the mean percentage of correct additions did not decrease significantly until 50 min of testing had elapsed. However, the number of additions attempted was significantly fewer than the last baseline day after only 10 min. These results indicate a strong interaction between sleep loss and time-on-test.

Schlegel, Gilliland, and Schlegel (1986) examined the effects of one night's sleep loss on the mathematical processing task found in the Criterion Task Set (CTS) (Shingledecker, 1984). The computerized test required an execution of two mathematical calculations (addition and subtraction) for each problem. There were three levels of difficulty on this mathematical processing task (low, moderate, and high). Twenty-five male and twenty-five female subjects were instructed to decide whether the result of a mathematical calculation was greater than or less than the value '5'. The effects of sleep loss produced significant increases in RT on all levels of difficulty, however, accuracy levels remained consistently high (97 %) and thus failed to reach significance.

Among the variety of mathematical processing tests used, the results appear to be more consistent. In most cases, speed or RT was significantly impaired, however, in some cases the impairment was dependent on task difficulty. On the other hand, accuracy levels remained very high on all tests, failing to be significantly degraded by the effects of sleep loss.

Memory Search Tasks

Memory search tasks are primarily associated with working memory encoding and storage processes (Eggemeier, 1988). Most memory search tasks involve some of the following processing stages: detection, recognition, memory search and comparison, and response selection.

In a two part experiment, Williams, Gieseking, and Lubin (1966), examined the effects of sleep loss on memory. In the first experiment, they examined the effects of one and two night's sleep deprivation on immediate recall for 40 Army enlisted men. In this experiment, a list of tape-recorded, high-frequency words were played to each subject. A single word was announced and spelled, after which, the subject was given 10 sec to write the word on a blank sheet of paper. After the word list was completed, the experimenter examined the subject's list to insure accurate recognition and spelling of each word. Then subjects were asked to recall as many words as possible, and to write them on a blank sheet of paper. The order of words was not important and guessing was discouraged. Subjects were given 5 min to complete the task. The authors also varied the length of practice (3 days versus 5 days) on different groups. After one night's sleep deprivation the mean number of words correctly recalled for both practice groups significantly decreased.

In the second experiment, Williams, Gieseking, and Lubin (1966), examined the effects of one night's sleep loss (34 hours) on delayed memory recall. Subjects were shown 25 pictures (from a total set of 75 pictures), one at a time, for exactly 10 sec, and then each picture was removed. The pictures were identification photographs extracted from a Army yearbook. Subjects were instructed to pay very careful attention to each photograph, and were told a recognition test would be given 24 hours later. The experimenters, through careful observation, made sure subjects closely examined each picture. After 24 hours, subjects were given all 75 pictures, shuffled, and were asked to sort the collection into two piles, one containing the 25 pictures they recognized, and the second containing the unidentifiable pictures. There was no time limit. When the sleep-deprived and control groups were compared on difference scores of the number of correct recognitions, a small decrement was found after one night's sleep loss, however, it failed to reach significance. This difference score provided an indication of the sleep loss effect on the memory trace storage or retrieval stage. The largest decrement was found in the sleep-deprived group after the first recovery night. On the recovery day, subjects had great difficulty recognizing pictures presented during sleep deprivation. Therefore, the sleep deprivation effect seemed to have its most significant impact on the memory-trace formation.

Elkin and Murray (1974) examined the effects of up to 55 hours sleep loss on short-term recognition memory. A digit probe test was used to assess memory. Each trial consisted of six 3-digit numbers, whereby a 3-digit string was presented every 2500 msec. At the completion of each list, a warning tone was sounded, followed by a 3-digit probe number. Twenty subjects were instructed to decide whether or not the probe was presented in the list, and were asked to rate on a six-point scale their confidence in their answer. To insure detection, subjects were asked to repeat each 3-digit number and to write it down on paper. Testing blocks were manipulated, in that one assessed immediate recognition memory, called the "No-Delay" condition, and the other assessed delayed recognition memory, called the "Delay" condition. The Delay condition varied from the standard delay of 2500 msec, by introducing a 20-sec delay between the number list presentation and the warning tone. After 37 hours of sleep loss, a significant increase in the number of copying errors was found. In addition, the sleep-deprived group consistently performed more poorly than the control group in the delayed recognition condition. However, no significant difference was found between the sleep-deprived and control groups in the immediate recall condition.

After 24 hours of sleep deprivation, Polzella (1975), examined its effects on short-term recognition memory using the probe-recognition paradigm of Wickelgren and Norman (1966). Using the theory of signal detection (TSD) sensitivity statistic, d', the author was able to estimate the strength of an item in memory. The task controlled for both proactive interference (i.e., PI, the number of stimuli prior to the to-be-remembered item) and retroactive interference (i.e., RI, the number of stimuli between the to-be-remembered item and the probe). In each experimental trial 1 to 13 pairs of digits or letters were visually presented to each subject for 250 msec, followed immediately by a 250 msec mask; thus 2 stimuli were presented every second. Following the mask, a probe item appeared for 500 msec. The probe item was a member of the stimulus set in half the trails. The subject was instructed to press either the 'yes' button or the 'no' button, depending on his choice. After the recognition decision, the subject was asked to make a confidence judgement. This judgement was followed by accuracy feedback, and the next block began 5 sec later. Each testing session lasted approximately 30 min and consisted of 160 trials. Four levels of PI (0, 1, 2, or 4 stimuli) and five levels of RI (0, 1, 2, 4, or 8 stimuli) were varied orthogonally over all the trials. Five male subjects participated in the study. The effect of sleep deprivation on d', or the TSD sensitivity statistic was highly significant, that is, after 24 hours of sleep loss sensitivity was dramatically reduced. Results showed no significant effect of sleep deprivation on mean RT; however, sleep deprivation increased the positive skew of the RT distribution. The RT results suggested that the occurrence of lapses increased under sleep deprivation, and these lapses were accompanied by memory deficits.

Specifically, the lapses impaired the encoding of stimuli into short-term memory, and subsequently prevented their encoding into long-term memory.

In a subsequent analysis, Polzella (1978), using the data obtained in the study discussed above (Polzella, 1975), examined the effects of 24-hour sleep loss on the response threshold statistic, ß, of TSD. The results indicated a significant decrease in ß after sleep deprivation. Therefore, the author concluded that subjects were *less cautious* in detecting the probes following sleep loss.

Glenville, Broughton, Wing, and Wilkinson (1978) examined the effects of one night's sleep loss on short-term memory. The short-term memory test was presented auditorially to subjects, and consisted of 8 digits, one digit presented every 500 msec. This was followed by a 6-sec delay during which subjects were instructed to write the series of digits on paper. Results indicated no significant effects of sleep deprivation on the percentage of correct digits or the percentage of correct digit strings.

Using a variation of the Sternberg memory test from the Criterion Task Set (CTS), Schlegel, Gilliland, and Schlegel (1986) examined the effects of a single night's sleep deprivation on recognition memory. Three levels of the memory search tests were used in which an initial set of 1, 4, or 6 letters were presented to the subjects for memorization. Following this, subjects were required to identify whether a randomly generated letter was a member of the memorized set. The results demonstrated a general increase in mean reaction time, however, there was no significant change in response accuracy under sleep loss.

Cumulatively, the memory test results after one night's sleep loss demonstrate a high degree of ambiguity. The number of items recalled or recognized after sleep loss showed no definitive trend among the different tests. Although few tests examined speed or accuracy data, those studies which investigated these measures found significant impairments. Obviously, a need exists for more research on memory ability after one night's sleep loss.

Spatial Processing Tasks

As outlined by Eggemeier (1988), spatial processing tasks are primarily associated with spatial information resources. Typically, these tasks involve some sort of object manipulation in space. These tasks require storage, transformation, and comparisons of visuo-spatial objects, and therefore are often associated with visual short-term memory.

Schlegel, Gilliland, and Schlegel (1986) used the spatial processing test from the Criterion Task Set (CTS) in an analysis of the performance effects after one night's sleep deprivation. In this test, subjects were instructed to compare a histogram of 2, 4, or 6 bars with a second histogram that was rotated either 0, 180, or 270 degrees. The results showed a general increase in RT following sleep deprivation. However, there was no significant change found in response accuracy after sleep loss.

Evidently, very few sleep deprivation studies have employed spatial processing tasks. Even though, Schlegel, Gilliland, and Schlegel (1986) found no significant effects on the CTS version, in the past, many spatial processing task have been found to be sensitive to other stressors (e.g., deep-sea diving, long-term isolation, drugs; see AGARD AMP Working Group 12 (1989) for review). More sleep deprivation research needs to be performed using spatial processing tasks.

Grammatical Reasoning Tasks

Grammatical reasoning tasks attempt to examine an individual's ability to manipulate grammatical information, specifically, addressing the processing functions associated with reasoning (Eggemeier, 1988). Reasoning in these tasks usually involve the generation or extraction and use of relational rules. Grammatical reasoning tasks primarily place demands upon working memory.

Haslam (1982) examined the effects of 90 hours of sleep loss on a 20-min grammatical ('logical') reasoning task. The author also examined the performance results after 24 hours of sleep loss for ten trained infantrymen. The paper-and-pencil test was adapted from Baddeley's (1968) 3-min reasoning test. The test had a number of short sentences, each followed by a pair of letters. The sentences attempted to describe the order of the two letters, and the subject was instructed to read each sentence and decide whether it was a true or false description of the letter pair which followed (e.g., "AB" - B follows A is 'True', whereas "BA" - B does not precede A is 'False'). The subject was instructed to systematically proceed through the test leaving no blanks. The experimenter emphasized speed and accuracy. The mean number of correct responses per page of the test appeared to deteriorate after one night's sleep deprivation. However, this was due to a decrease in the number attempted rather than an increase in errors.

Schlegel, Gilliland, and Schlegel (1986) found significant increases in mean RT on an adapted version of Baddeley's (1968) verbal reasoning test after one night's sleep deprivation. The test - the grammatical reasoning test of the Criterion Task Set - substituted symbols for the letters used in Baddeley's task, and the test was administered on a computer rather than on paper. Otherwise, the test format remained the same. Results demonstrated an increase in the mean verbal reasoning RT as a function of sleep loss. However, there was no significant change found in response accuracy after sleep loss.

On the other hand, Farmer and Green (1985) examined the effects of one night's sleep loss on the original version of Baddeley's (1968) test of verbal reasoning (same as the test described above, except it was 3 min in length and presented on a computer), and found no significant effect on mean verbal reasoning RT.

Once again, the performance results after one night's sleep loss are inconsistent. The RT data are contradictory; one study found a significant decrease in RT, and another found no significant decrease. However, in this case, all researchers used adapted versions of the same, fundamental grammatical reasoning test. The true effects of one night's sleep loss on grammatical reasoning are yet to be determined.

Studies Relevant to Motor Output Resources

In this section, tracking task research (e.g., pursuit, compensatory, step-input, unstable) following one night's sleep loss will be examined. Once again, as the studies are reviewed, special attention should be made to the inconsistent results found across different experiments, and the variety of tests employed within and between different experiments.

Tracking Tasks

These tasks are assumed to draw upon the motor output resources by requiring continuous, or semi-continuous manual control responses. Tracking tasks presumably place minimal demand upon resources associated with perception and central processing.

Gibbs, Leonardo, and Rowlands (1968) examined the effects of sleep deprivation on two types of tracking tasks: a) step-input tracking, and b) mirror tracing. In the step-input tracking task, a target light was presented for 2 sec at any of five positions. Twelve male subjects were instructed to align the pointer, using a hand wheel, with the target. The sequence of target movements, on different steps, varied probabilistically. A stressalyzer was used to record subject data. The mirror tracing task required each subject to trace an image of a brass star with a metal stylus, while the subject looked into a mirror. Subjects were instructed to perform these tasks as rapidly and as accurately as possible, and were given complete knowledge of results. Results showed a sharp deterioration in tracking ability after 20 hours without sleep, and an even greater decrement developed after 36 hours of sleep loss. The mirror tracing task was far less vulnerable to the effects of sleep loss than the step-input tracking task, and showed no significant deterioration.

Using the unstable tracking task from the Criterion Task Set (CTS), Schlegel, Gilliland, and Schlegel (1986) examined the effects of one night's sleep deprivation on tracking performance. Each subject was instructed to maintain the vertical position of a symbolic airplane on a defined line in the center of the display by turning a control knob. The task dynamics magnified the control error and prevented stable control, which may result from extensive practice. Tracking performance was significantly impaired by the effects of 24-hour sleep loss for both the absolute mean tracking error and the number of edge violations. On the lower levels of unstable tracking (where tracking is generally easy and frequently becomes vigilant-like), the absolute mean tracking errors were strongly degraded by sleep loss.

Hockey (1970) examined the performance on a dual task consisting of a pursuit tracking task and a signal detection task after 30 hours of sleep loss. The tracking task was defined as the primary task, and the signal detection task as the secondary task. In the tracking task, the tracking window was centered in the subject's visual field. As the target pointer moved laterally across the window, the subject was instructed to keep a second pointer aligned with the target. The second pointer was controlled by a handle in the vertical plane of the subject's right hand. In the monitoring task, the subject was instructed to press one of six buttons which corresponded to the activated light (one of six lights), which was placed at either 20, 50, or 80 degrees around the periphery of the tracking window. Twelve subjects participated in the study and each session lasted 40 min. The results showed that the mean time-on-target (TOT) score decreased significantly from the first to the fourth 10-min period. However, these results must be interpreted in terms of the secondary, monitoring task, and therefore are not a true indication of independent tracking performance.

In another dual task study, Farmer and Green (1985) examined the effects of one night's sleep loss on a compensatory tracking task and a monitoring task. A two-axis compensatory tracking task was employed, whereby each subject was instructed to move the joystick in order to maintain the cursor position at the center of the display. A complex trigonometric forcing function was added to provide unpredictable cursor movements. In the monitoring tasks, each subject was instructed to watch the two illuminated columns to the right and left of the tracking display. During the task, one column would 'roll', or increase in height, and the other column would decrease. The subject was asked to press the key which corresponded with the 'rolling' column. The experimental session lasted 20 min. The results indicated that the root mean square (RMS) error on the tracking task significantly increased as a function of sleep deprivation. As with Hockey (1970), these results are difficult to evaluate because of possible interaction effects with the monitoring task.

Lack of Standardization and Methodological Problems

An analysis of one night's sleep deprivation literature indicates ambiguous performance results. On the other hand, performance-based research following more than one night's sleep loss clearly shows information processing degradations. A number of authors have critiqued sleep deprivation research from a methodological point of view (Wilkinson, 1965; Meddis, 1982; Webb, 1982; Gaillard and Steyvers, 1989). The examination of experimental research involving one night's sleep loss reveal a lack of standardization in the selection of tests, and in the methods by which the tests are administered.

In the study of sleep deprivation, it is necessary to select tests which have built a strong psychometric history. Traditionally, psychometric development involves a long and detailed process prior to the creation of a standardized performance test. Gaillard and Steyvers (1989) stress the importance of choosing tests which have a solid theoretical basis. They state that a test should be thoroughly studied in the laboratory and the psychological processes measured by the test should be well documented, and presented in a theoretical framework. As Webb (1982) noted, a performance test requires standardization on a normative population before it can serve as a diagnostic measure for a selected sub-sample performing under the effect of some variable (e.g., sleep deprivation). Standardized tests help to provide solutions to two fundamental problems in basic performance research, that is, acceptable test reliabilities and validities.

Similarly, the administration of the test must be in accordance with accepted experimental methodologies. For example, subjects must be sufficiently trained on the test before performing under sleep deprivation. Also, subjects should be tested at the same time of day, every day, in order to eliminate circadian effects. Subjects should also be tested after they have recovered from sleep loss, to determine if baseline performance is regained. If this is the case, then the performance decrement can in fact be related to the effect of sleep loss. Methodological considerations such as these are crucial to an accurate assessment of performance decrements following sleep loss.

For these reasons, the effects of one night's sleep loss will be examined using an accepted, standardized and experimentally validated test battery, called the NATO/AGARD Standardized Tests for Research and Environmental Stressors (STRES) Battery.

NATO/AGARD STRES Battery

The STRES Battery was developed by the Advisory Group for Aerospace Research and Development (AGARD) Aerospace Medical Panel (AMP) Working Group 12 (AGARD AMP Working Group 12, 1989). The main objective of the STRES Battery was to provide a core of well-accepted performance tests for use by applied researchers. The STRES Battery is comprised of seven tests, which include: Reaction Time, Mathematical Processing, Memory Search, Spatial Processing, Unstable Tracking, Grammatical Reasoning, and Dual Task (unstable tracking with concurrent memory search). These performance tests were selected on the basis of the following criteria: a) strong evidence of reliability, validity, and sensitivity, b) solid psychometric history, by demonstrating an ability to assess stressor effects, c) sensitivity to stressors after a short testing duration, d) language-independence, e) solid theoretical background in Human Performance Theory (HPT), and f) ability to be implemented on simple and easily-accessible computer systems.

The development and implementation of the STRES Battery has placed significant emphasis upon standardization. The AGARD AMP Working Group 12, representing an acknowledged and authoritative group of international applied researchers, have carefully constructed the STRES Battery, and have recommended it for stress research.

In addition to the standardized test battery, the developers also specified a standardized data base format to facilitate the exchange of performance data between researchers using the STRES Battery. A central data base is currently being established for data storage and retrieval. This cumulative stressor database will be easily accessible by the international community of applied researchers.

An advantage of the STRES Battery is that it allows for both 'narrow-band' and 'broad-band' approaches (Hockey and Hamilton, 1983) to the study of stressor effects (e.g., sleep deprivation, noise, heat, cold, etc.). The narrow-band approach, which is not important to this particular study, describes an investigation of a variety of stressor effects on a single test. Generalizations about different stressors can be gained through this technique. In this study, a broad-band strategy was important. A broad-band approach investigates the effects of a single stressor (in this case, one night's sleep deprivation) on the various tests, such as those included in the STRES Battery.

This sleep deprivation study will follow the broad-band approach. By using the STRES Battery, an attempt will be made to uncover the different information processing resources which are truly impaired as a result of one night's sleep loss. It is believed that the use of a standardized, reliable, and validated test battery will yield an accurate assessment of performance following one night's sleep loss.

CHAPTER II

METHOD

Subjects

Subjects were recruited from a subject pool maintained and managed at the U.S. Air Force Armstrong Laboratory (AL). The subject pool exists to support human performance research at AL. Twelve subjects participated in this sleep deprivation study; however, one subject left after the second day of the experiment and was not replaced. Subjects were paid approximately five dollars per hour for their participation. In addition, all subjects were required to be in good health and lack any drug dependency, including alcohol (self-reported). Subjects were requested to refrain from alcoholic beverages during the week of the experiment. Subjects were male, college students between the ages of 18 and 30, right-hand dominant, and had normal or corrected-to-normal vision (20/20). Subjects who wore contact lenses were not allowed to participate, as around-the-clock activities during the sleep loss night might hinder their performance, if contact lenses had to be removed.

Only subjects with no prior experience in a sleep deprivation study and little personal experience with total sleep deprivation were permitted to take part in this investigation. Also, subjects were selected on the basis of normal sleep habits (i.e., typically go to sleep between 2200 and 2400, and awake between 0700 and 0900). In order to monitor these behaviors, subjects were required to complete a Food and Sleep

Diary (see Appendix A) on a daily basis. The Diary was completed by subjects one week prior to the experiment starting date, and also during the actual week of the experiment - ending with the final day of the experiment.

The subjects were given complete information concerning their participation, and were free to withdraw from the study at any time. A brief experimental overview given to the subjects appears in Appendix B. No deception was employed, and subjects were thoroughly debriefed at the conclusion of the experiment.

The STRES Battery

The Standardized Tests for Research with Environmental Stressors (STRES) Battery was administered to all subjects on a computer system. As described before, the STRES Battery includes the following performance tests: Reaction Time, Mathematical Processing, Memory Search, Spatial Processing, Unstable Tracking, Grammatical Reasoning, and Dual-Task (unstable tracking with concurrent memory search). All of the aforementioned tests were administered in this experiment; however, the results of the Dual-Task were not analyzed in the present study. Detailed reviews on the background, reliability, validity, sensitivity, normative data, and technical specifications for each test are presented in AGARD AMP Working Group 12 (1989), nevertheless, brief descriptions of each test will be presented here.

Reaction Time Test

The Reaction Time Test was constructed so that the separate reaction process stages (i.e., stimulus encoding, response choice, motor programming, motor activation, and response execution) could be tested and analyzed. At the start of the test, the subject placed index and middle fingers of both hands on the appropriate response keys. The subject was instructed to press the appropriate response key when the stimulus appears. The instructions varied according to the experimental condition, or trial block (see below). The stimulus was equally likely to be 2, 3, 4, or 5, and was equally likely to appear on the left side or the right side of the display. Each stimulus appeared for 1 sec, followed by a blank display for 1 sec. The period between any two stimuli was always 1 sec. Each trial block lasted 2 min, and consisted of 60 trials. Each block was preceded by brief instructions concerning the experimental condition. During the experimental testing sessions, no error feedback was provided. During the practice session, if the subject responded incorrectly within the first second, feedback was displayed ("error") after the normal 1-sec stimulus presentation; however, if the subject responded incorrectly during the blank-display period, then the error message was shown immediately for 500 msec. The first seven trials were for practice or 'warm up', and were not included in the analysis. The entire Reaction Time Test lasted 15 min, and was comprised of the following experimental conditions, administered in this order:

1.) ***Basic*** - The subject placed the left-hand fingers on the left hand response keys A and B, and the right-hand fingers on the right hand response keys C and D. The subject was instructed to respond to digits appearing on the left side of the display with the left hand, and to respond to digits appearing on the right side of the display with the right hand. The stimuli were the digits 2 through 5. The subject used response key A or C for 'low' digits (2 or 3), and response keys B or D for 'high' digits (4 or 5), as shown in Figure 1. The subject was instructed to press the appropriate response key once, as quickly and as accurately as possible. All other test characteristics were the same as described above.

2.) ***Coded*** - This experimental condition was identical to the Basic condition, with the exception of degraded stimuli. Four degraded versions of each digit were created

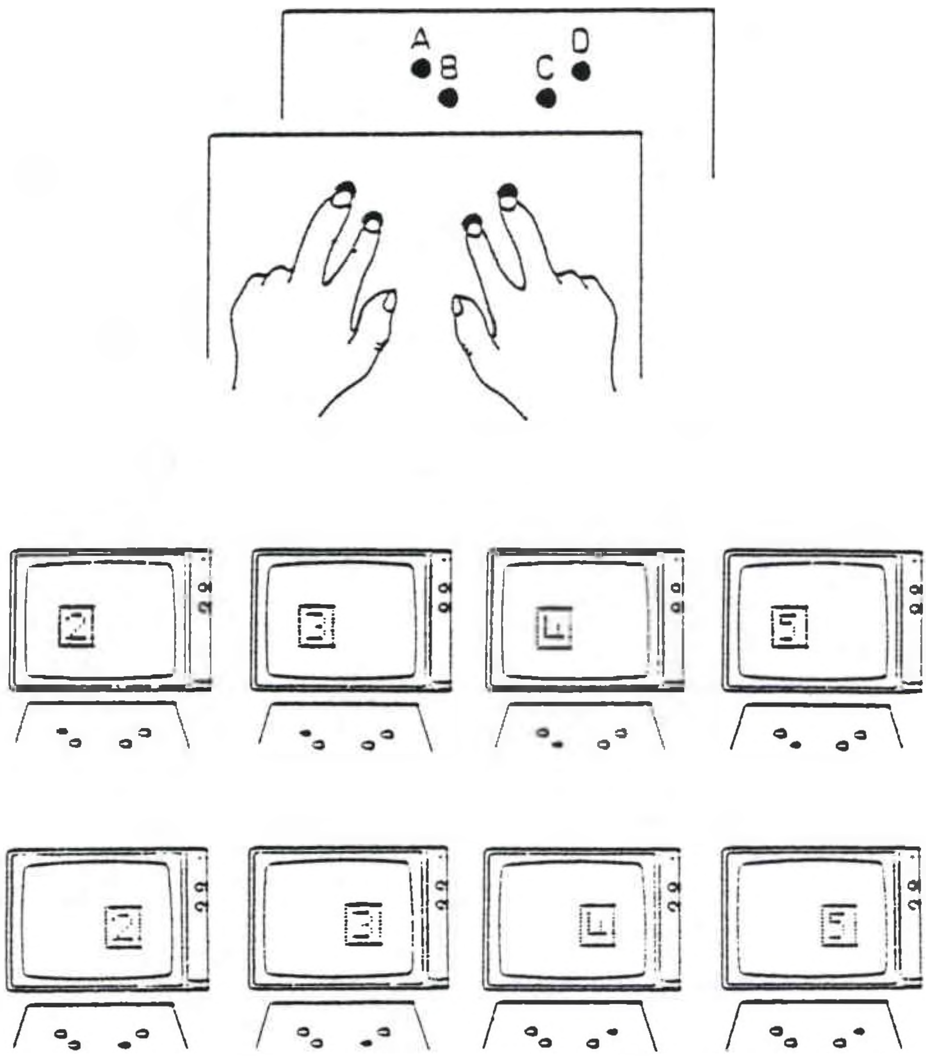

Figure 1. Finger arrangements and stimuli and responses on the Reaction Time Test.

by moving 10 dots from the rectangular frame that surrounded each stimuli towards the central digit stimulus.

3.) ***Time Uncertainty*** - This condition was also identical to the Basic condition, with the exception of two changes. First, the stimuli were presented using irregular and variable interstimulus intervals (ISIs), chosen randomly between 2000 and 1000 msec. Second, as a result of the varying ISIs, there were only 22, instead of 60 stimuli.

4.) ***Double Responses*** - Identical to the Basic condition, except that three response keys were pressed when the stimulus was presented, rather than the typical single key-press. In this condition, an 'A' response became an 'ABA' response sequence; 'BAB' instead of 'B'; 'CDC' instead of 'C'; and 'DCD' instead of 'D'. RT was defined as the interval between stimulus presentation and the first key response; response execution time was defined as the interval between the first and last key-press.

5.) ***Inversion*** - Also identical to the Basic, except that the stimulus-response compatibility was switched, that is, left-hand key responses were required for right-hand stimuli, and right-hand key responses were required for left-hand stimuli.

6.) ***Basic*** - same as described before.

For each session the following data were collected: 1) mean RTs for all responses, 2) mean RT standard deviation for all responses, and 3) mean response accuracy, as measured by number of correct, incorrect, and missed responses.

Mathematical Processing Test

The Mathematical Processing Test was included primarily because of its ability to place demands upon working memory processing resources. In general, the test required the subject to retrieve information from long-term memory, update information in working memory, perform sequential arithmetical calculations, and perform numerical comparisons. The subject watched the screen for the presentation of the arithmetical problem. The problem consisted of three single digit numbers (1-9), separated by two arithmetical operators (+ or -), and followed by =, as shown in Figure 2. The correct answer could be any number between 1 and 9, with the exception of 5. The subject was instructed to respond to each problem by pressing one of two keys, indicating whether the answer was greater than ('>') or less than ('<') 5. It was equally probable that the correct answer was greater than or less than 5. The subjects were given 15 sec to provide an answer, after which duration the problem was erased and the screen blanked. After a varying ISI between 3000 and 5000 msec, a new problem was presented. The duration of each trial block was 3 min. During the experimental sessions no error feedback was provided, however error feedback was given during the practice session. Subjects were given the opportunity to read the test instructions, and given 10 demonstration, or 'warm-up' trials prior to the start of the experimental trials.

The following data were collected for each session: 1) mean RT for all responses, 2) mean RT standard deviation for all responses, and 3) mean response accuracy, as measured by number of correct, incorrect, and missed responses.

Memory Search Test

The Memory Search Test is based the additive-factor methodology and paradigm established by Sternberg (1969). Basically, this test required the performance of many, sequential operations including: detection, recognition, memory search and comparison, and response selection. This test used the Fixed Set procedure (i.e., the same memory set was presented to the subject and was followed by many probe items). At the start of the

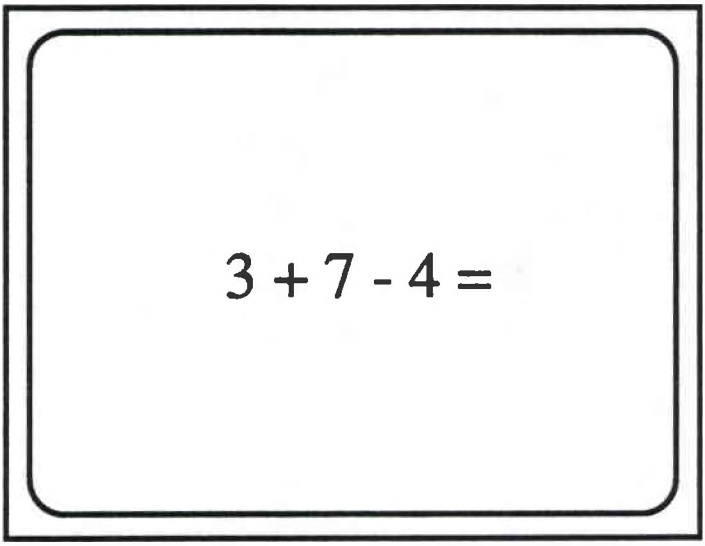

Figure 2. Sample stimulus display from the Mathematical Processing Test.

test, the memory set items were all simultaneously presented in the center of the display. The subject was instructed to press one of the two response keys to blank the display after viewing the memory set. After 1 sec, the first probe appeared, beginning the 3-min testing period. Positive probe items were equally likely to match one of the memory set items, whereas negative probe items were chosen randomly from all letters not found in the memory set. During each trial the following sequence occurred repeatedly: 1) the probe item was displayed, 2) the subject pressed one of the two response keys ('YES' or 'NO') as quickly as possible, or the probe disappeared after 5 sec, 3) the display blanked for 1 sec. RT was defined as the time elapsed between the presentation of the probe item and the activation of the either response key. Each session consisted of two 3-min blocks. The first block used a memory set size of two items (Mset = 2), and the second used a memory set size of four (Mset = 4). During the experimental sessions no error feedback was given, however, error feedback was provided during the practice session.

For each session the following data were collected: 1) mean RT for all responses, 2) mean RT standard deviation for all responses, and 3) mean response accuracy, as measured by number of correct, incorrect, and missed responses.

Spatial Processing Test

The Spatial Processing Test was used to measure visual short-term memory, by examining subject's ability to rotate histograms mentally, and to make judgments following those mental rotations. In this test, a pair of bar graphs, or histograms, was presented one at a time for each trial. Each histogram consisted of four bars ranging in height from one to six units. The subject was instructed to memorize the shape of the first histogram (labeled '1'), decide whether the shape of the second histogram (labeled '2') was the same or different, and then press one of the two response keys which corresponded to 'same' or 'different'. The first histogram was displayed at the zero degree orientation, and the second histogram was either 90 or 270 degrees out of standard position, as shown in Figure 3. During each experimental trial the following sequence occurred repeatedly: 1) the first histogram was displayed for 3 sec, 2) the display blanked for 1 sec, 3) the second histogram was displayed continuously until either a response was made, or 15 sec had elapsed, 4) the display blanked for 1 sec. The testing session lasted 3 min. Reaction time and accuracy feedback were provided in the practice session, however, no feedback was given in the experimental sessions.

The following data were collected after each session: 1) mean RT for all responses, 2) mean RT standard deviation for all responses, and 3) mean response accuracy, as measured by number of correct, incorrect, and missed responses.

Unstable Tracking Test

The Unstable Tracking Test was used to assess the subject's ability to execute continuous manual control responses. In general, the subject was instructed to maintain the position of a cursor between two center markers and avoid control losses (i.e., when the cursor exceeded the marked boundary on the display) throughout a tracking period. The cursor moved horizontally, with the central position in the middle of the display. Specifically, the subject was expected to move the cursor to the right in response to leftward movements of the cursor, and to move the joystick to the left in response to rightward movements of the cursor, in an overall effort to keep the cursor in the center of the display. The display for the Unstable Tracking Test is shown in Figure 4.

A maximum tracking loop time delay of 50 msec (+/- 5%) helped to create the unstable tracking dynamics, which became exacerbated by the subject and by noise in the joystick

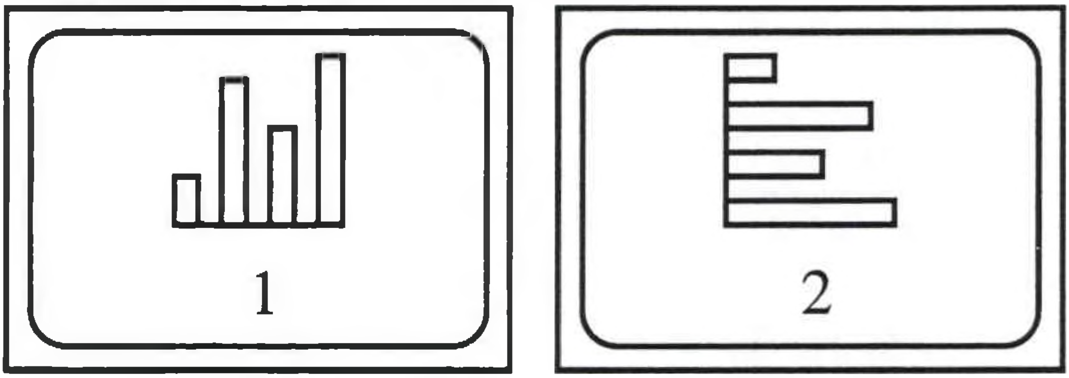

Figure 3. Sample display of the first and second histograms in the Spatial Processing Test.

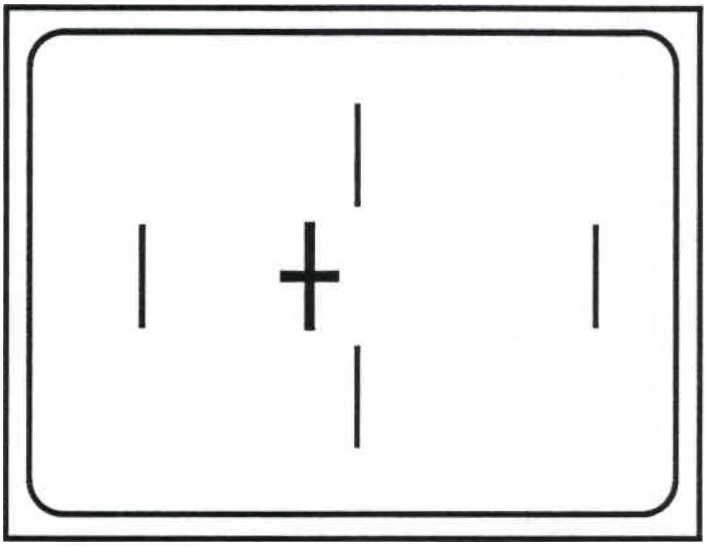

Figure 4. Sample display in the Unstable Tracking Test.

digitization process. If a control loss occurred the cursor was reset to the center of the display. The test lasted 3 min.

The mean RMS error and mean number of control losses were collected for each experimental session. A control loss refers to a situation during a trial when the cursor reaches the edge of the screen.

Grammatical Reasoning Test

The Grammatical Reasoning Test placed heavy demands on working memory, and examined the subject's ability to manipulate grammatical information. Basically, the test required the subject to compare the accuracy (correct or incorrect) of two sentences which describe the order of two adjacent symbols within a total set of three symbols (see Figure 5). The subject was instructed to press the 'same' response key if both sentences were true, or if both were false; however, if one sentence was true and the other was false, the subject was instructed to press the 'different' response key. Using Figure 5 as an example, the subject would compare the accuracy of the first two sentences (i.e., *& AFTER #* and ** BEFORE &*) with regard to the third sentence (i.e., **&#*). The first sentence is incorrectly describing the third sentence, and the second sentence is correctly describing the third sentence; therefore the subject would press the "different" response key to signify the different truth values. Thirty-two problems are presented during each session. Each of these problem combinations are thoroughly described in AGARD AMP Working Group, 1989). Each grammatical problem was presented in the middle of the display, and remained there until either the subject responded, or a 15-sec delay period elapsed. After a 1-sec ISI, the next problem was presented. Each testing session lasted 3 min. Error feedback was provided to subjects during the practice session, however, no feedback was given during the experimental sessions.

Figure 5. Sample stimulus display for the Grammatical Reasoning Test.

For each session the following data were collected: 1) mean RT for all responses, and 2) mean RT standard deviation for all responses, and 3) mean response accuracy, as measured by number of correct, incorrect, and missed responses.

Dual-Task

The Dual-Task is the combination of the Unstable Tracking and Memory Search task, and it measured the ability to divide attention between two activities. During the concurrent presentation of these tasks, each proceeded as previously described. Therefore, the first, 3-min period was devoted to a Mset = 2, and the second to a Mset = 4. Subjects were instructed to allocate equal priority to the tracking and memory search tasks.

In the Dual-Task the cursor was initially centered on the display screen. As soon as the subject pressed the response key to indicate that he had memorized the memory set, the 10-sec warm-up period of the Unstable Tracking Test began. The memory set remained on the screen for the first nine sec of this period. After 10 sec elapsed, the first probe item was presented and the three-min test began.

Software and Apparatus

The STRES Battery was operated on two Zenith 248 computers, and implemented using the Micro Experimental Laboratory (MEL) (Version 2.0) third-generation integrated software system (Schneider, 1988). MEL software system provides real-time data acquisition, and immediate access to a variety of statistical tests. MEL maintains millisecond-precision timing with high-speed text and graphics presentation capabilities.

In the tracking test, a Data Translation DT2808 analog-to-digital board was used. A joystick from OEM Controls, Inc.(Part No. M54M 5705) was used to control the cursor movement in the Unstable Tracking and Dual Task Tests.

Design

The eleven subjects were divided into three testing groups consisting of two groups with four subjects each, and one group with three subjects. For each group, the entire experimental period consisted of one practice session, four rested sessions (i.e., two "pre-sleep loss" rested sessions and two "post-sleep loss" rested sessions), and two sleep-deprived sessions (i.e., after approximately 18- and 24-hours of sleep deprivation). In total, these sessions covered a two-week period requiring seven days of testing. The sequence of the experimental sessions is shown in Table 1.

Each subject was tested at the same time on all seven days, with the exception of the 18-hour sleep deprivation session, which occurred approximately 6 hours prior to the normal start time for the rested and 24-hour sleep loss testing sessions. Two computers were used; consequently subject testing occurred in groups of two. Subjects were separated from each other during testing by several wall partitions. Subjects were scheduled at 150 min intervals, with the first two subjects beginning their sessions at 0800, and the second two subjects beginning at 1030.

The STRES Battery tests were randomized and counterbalanced into two presentation orders, which were then divided equally across the subjects. The presentation orders are shown in Table 2 for each subject.

Table 1. Sequence of experimental sessions.

Session 1	Session 2	Session 3	Session 4
Rested Day 1	Rested Day 2	18-Hour Sleep Loss	24-Hour Sleep Loss

Session 5	Session 6
Rested Day 3	Rested Day 4

Table 2. STRES Battery test presentation orders for the experimental sessions.

Subjects 1, 3, 5, 7, 10

Session 1	Session 2	Session 3	Session 4	Session 5	Session 6
Track*	Gramm	Track	Spatial	Gramm	Track
MemSrch*	RT	MemSrch	Track	RT	Spatial
Dual*	______	Dual	Math	______	MemSrch
Spatial*	Math	Spatial	MemSrch	MemSrch	Dual
Math*	MemSrch	Math	Dual	Math	Math
______	Track	______	______	Spatial	______
RT*	Spatial	RT	RT	Track	RT
Gramm*	Dual	Gramm	Gramm	Dual	Gramm

Subjects 2, 4, 6, 8, 9, 11

Session 1	Session 2	Session 3	Session 4	Session 5	Session 6
Gramm	MemSrch	Gramm	Gramm	Math	Gramm
RT	Math	RT	RT	MemSrch	RT
______	Spatial	______	______	Track	______
Track	Track	Track	Spatial	Spatial	Track
Spatial	Dual	Spatial	Track	Dual	MemSrch
MemSrch	______	MemSrch	Math	______	Dual
Dual	RT	Dual	MemSrch	RT	Spatial
Math	Gramm	Math	Dual	Gramm	Math

* Key to Abbreviations

RT	- Reaction Time test (including all six conditions)
MemSrch	- Memory Search test(including both Set sizes)
Math	- Mathematical Processing test
Spatial	- Spatial Processing test
Gramm	- Grammatical Reasoning test
Track	- Unstable Tracking test
Dual	- Dual-Task
______	- The blank line indicates the session halfway point and CPU change

Table 3 provides a summary of the total duration for each test during each experimental session. Also provided in Table 3 is a summary of the amount of formal training, or practice that each subject was given on all tests prior to the start of the experimental testing. In total, each subject spent approximately six hours of practice on the STRES Battery tests. The practice trials provided subjects with stabilized performance on the tests. In addition, some experimental tests provided practice trials prior to the experimental trials to eliminate any warm-up effects.

Procedure

The experiment was conducted at the U.S. Air Force Armstrong Laboratory, located at Wright-Patterson AFB, Ohio. Subjects were required to read and sign a standard consent form (see Appendix C) when they arrived on the first day of the experiment. The consent form included a brief description of the study and description of the stressor to be administered. The purpose of the consent form was to inform each subject of the risk, responsibility, and liability involved with the study. Subjects were then given detailed verbal instructions describing the STRES Battery and the procedures to be followed during both the practice and experimental sessions.

Depending on the group they were assigned to, subjects reported to the laboratory to gain practice on the STRES Battery on Tuesday or Wednesday of Week 1. The standard training schedule required approximately six to seven hours to complete. As specified by AGARD AMP Working Group 12 (1989), the standard practice schedule shown in Table 3 was designed to eliminate learning effects, and lead to stabilized performance.

As a part of this experiment, subjects also responded to the NASA Task Load Index (TLX) - a subjective workload assessment technique (Hart and Staveland, 1987). During

Table 3. Summary of test durations in each experimental session, and amount of practice.

Test	Total test duration (min)	Practice schedule (blocks)
Reaction Time	15	Basic: 16 Other conditions: 4 each
Mathematical Processing	4	10
Memory Search	8	10/memory set size
Spatial Processing	4	10
Unstable Tracking	4	10
Grammatical Reasoning	4	8
Dual-Task (not analyzed)	8	5/memory set size

the practice sessions, subjects received instructions on the use of the NASA TLX, practiced subjective ratings of the various STRES Battery tests, and completed the necessary NASA TLX weightings required for future analyses. The NASA TLX ratings were not analyzed in this study, but will be analyzed and discussed in future reports.

Each subject was then seated in front of one of the two computers, and began the practice session. The STRES Battery Tests were consistently divided between the two computers throughout the practice and experimental sessions. One computer was used solely for the Reaction Time tests and the Grammatical Reasoning Test, while the other computer was dedicated to the Unstable Tracking, Memory Search, Dual Task, Spatial Processing, and Mathematical Processing Tests. When the subjects had completed all the necessary tests at their computers, they switched computers, and completed the remaining tests.

After completion of the practice session, each subject was assigned to a particular testing time periods (i.e., 0800 or 1030). They were instructed to arrive at the laboratory, each testing day, approximately 20 min prior to the scheduled testing time. They were also reminded to maintain their Food and Sleep Diaries.

During each experimental testing session, in addition to collecting performance (i.e., STRES Battery) and subjective (i.e., NASA TLX) data, physiological data were collected. The physiological data were collected as part of parallel study conducted by AL researchers. Specifically, three channels of EEG were monitored, one channel of eyeblink (EOG) activity, and one channel of heart (ECG) activity. To record these data, eight electrodes were applied to each subject. This process of applying the electrodes was performed at the beginning of each session. The physiological data were not analyzed in this study, but will be analyzed and discussed in future reports.

After subjects were connected to the electrodes, they were seated at the appropriate computer as designated by the STRES Battery presentation order (see Table 2). Before each experimental test began, the subject was required to enter subject and experimental condition information, in an effort to meet the requirements of the STRES Battery database and data exchange policy, and to assist the researcher in maintaining accurate data files for future analysis. Upon entering this information, testing was initiated. Every test was prefaced by the presentation of standardized instructions on the computer monitor. Then, subjects were presented the stimulus sequence according to the test description. The performance data and condition information was automatically stored on the computer. At the completion of each test or test condition (e.g., Reaction Time - Basic Condition, Memory Search - Mset = 2, etc.), the subjects were instructed to complete the NASA TLX ratings. Subjects were then required to enter additional subject and experimental condition information before the next test began. Approximately halfway through each experimental session, subjects were required to switch computers, and complete the remainder of the tests. After all experimental tests had been completed, the subjects were disconnected from the electrodes, and given specific instructions concerning logistical issues for the next testing session.

On Thursday, subjects reported to the laboratory at their scheduled times for a rested testing session. After approximately 75 min of testing, the subjects were excused, and were free to leave the testing facilities. On Friday, subjects reported to the laboratory for another rested testing session. The Thursday and Friday test sessions provided pre-sleep deprivation baseline performance measures. Upon leaving on Friday, they were requested to refrain from sleep during the day, and were asked to return to the laboratory at 2200. When the subjects convened at 2200, they were kept awake (monitored by the researcher) until the experimental sessions began. The researcher was in continuous visual contact with the subjects throughout the sleep deprivation period. There were no formal activities scheduled during this 24-hour vigil; however, subjects were allowed to read, listen to music, watch television, play games, and take group walks under supervision. Subjects were given up to three, 6-oz fruit juice drinks, popcorn, potato chips, and water during the sleep loss period. They were not allowed to drink fruit juice, or eat food after 0600.

Subjects were tested early Saturday morning, with the first group of subjects tested between 0315 to 0430, and the second group tested between 0430 and 0545. This session constituted an 18-hour sleep deprivation period. Subjects were again tested at the normal testing time (i.e., 0800 and 1030), which constituted a 24-hour sleep deprivation period. After the subjects completed testing, they were driven home by a non-sleep-deprived researcher.

Subjects were allowed to recover from the 24-hour sleep decrement on Saturday in an attempt to return to baseline performance. They were instructed to get normal amounts of sleep, and to refrain from alcohol.

On Sunday, subjects reported to the laboratory, at their normally scheduled time periods for additional rested testing. Subjects left after the testing session was completed. Finally, on Monday, subjects completed their rested testing sessions at the normally scheduled times. The Sunday and Monday test sessions provided post-sleep deprivation performance results.

CHAPTER III

RESULTS

The following experimental results are divided into three main sections, which represent the organizational framework established in the introduction to this study. Based on current information processing theories (Sanders, 1983; Wickens, 1984; AGARD AMP Working Group, 1989), the STRES Battery tasks can be classified into the three primary stages of information processing: perceptual input (perception), central processing (decision), and motor output (action). These three stages of information processing create the structure for the following test results as shown in Table 4.

The analytic strategy used in this study basically examined statistical differences existing between the rested tests versus the sleep deprived tests. Since the data collected during the rested testing sessions occurred at approximately the same time on each day, multivariate analyses of variance (MANOVAs) were performed on the linear combination of the dependent measures for each test (within each of the three information processing resources) to determine if statistical differences existed across the four rested days. Based on the results of these MANOVAs, either reliability analyses were conducted to ensure the appropriateness of combining data across rested testing sessions, or additional univariate analyses of variance (ANOVAs) were conducted to determine which dependent measures differed across the rested days. Since the two sleep loss sessions occurred approximately

Table 4. Classification of STRES Battery tests into the primary information processing stages.

Information Processing Stage/Section	STRES Battery Test
I. Perceptual	Reaction Time
II. Central Processing	Memory Search
	Mathematical Processing
	Spatial Processing
	Grammatical Reasoning
III. Motor Output	Unstable Tracking

3-4 hours between each other, these sessions were not grouped together, and were analyzed separately. Significant physiological differences are known to exist between these different time periods (e.g., Colquhoun, 1970), and grouping these sessions together could obscure performance differences.

Several dependent variables were of interest in this sleep deprivation study, depending on the test(s) under examination. For the Reaction Time tasks, Memory Search, Mathematical Processing, Spatial Processing, and Grammatical Reasoning tests, the following three variables were of primary interest: (1) mean reaction time to various test stimuli, (2) standard deviation of mean reaction times, and (3) response accuracy, as measured by percentage correct. For the Unstable Tracking task, the following two variables were of primary interest: (1) number of control losses, and (2) root mean square (RMS) error. The data for each session were averaged across subjects and trials. Data were collected and analyzed for 11 subjects, as one subject left the experiment after the second rested session. This subject was not replaced.

Performance Differences Between Rested Testing Sessions

Three multivariate analyses of variance (MANOVAs) were performed on the linear combination of the "test-dependent variable combinations" for each information processing resource to determine if statistical differences existed between the four rested testing sessions. [Note: The linking of each test or test condition (e.g., Reaction Time-Basic, Unstable Tracking, etc.) with a dependent variables (e.g, RT, accuracy, RMS error, etc.) shall be referred to as a "test-dependent variable combination".] Huberty and Morris (1989) advocate the use of MANOVAs when studying multiple systems, or subsystems, of variables for comparative purposes, as is the case in this investigation. The MANOVA procedure is the most appropriate and statistically powerful first step in determining whether on not there are any overall performance differences between the rested days.

The MANOVA for the perceptual resource tested the linear combination of 15 test-dependent variable combinations for the Reaction Time Test, including: Basic-Reaction Time (RT), Coded-RT, Time Uncertainty-RT, Double Response-RT, Inversion-RT, Basic-Standard Deviation (SD), Coded-SD, Time Uncertainty-SD, Double Response-SD, Inversion-SD, Basic-Percent Correct (PC), Coded-PC, Time Uncertainty-PC, Double Response-PC, and Inversion-PC. The MANOVA for the central processing resource tested the linear combination of 15 combinations, including: Memory Search (Mset=2)-RT, Memory Search (Mset=4)-RT, Mathematical Processing-RT, Spatial Processing-RT, Grammatical Reasoning-RT, Memory Search (Mset=2)-SD, Memory Search (Mset=4)-SD, Mathematical Processing-SD, Spatial Processing-SD, Grammatical Reasoning-SD, Memory Search (Mset=2)-PC, Memory Search (Mset=4)-PC, Mathematical Processing-PC, Spatial Processing-PC, Grammatical Reasoning-PC. The MANOVA for the motor output resource tested the linear combination of RMS error and number of control losses for the Unstable Tracking Test.

Table 5 provides of summary of the multivariate results for each information processing resource. No significant differences between rested testing sessions were found for the perceptual and motor output resources; therefore indicating that post-sleep deprivation performance (or recovery performance) was complete. However, multivariate significance, using Pillai-Bartlett trace, was found for the central processing resource ($F_{(45,54)} = 1.91$, $p < .05$), indicating that performance differences existed among the rested days across the 15 test-dependent variable combinations. Subsequently, one-way within-groups univariate ANOVAs were used to test for performance differences across the four

Table 5. Statistical summary table for information processing resource MANOVAs across rested testing sessions.

Information Processing Resource	**p-Value**
Perceptual Tasks	NS
Central Processing Tasks	<.05
Motor Output Tasks	NS

rested days on each central processing test-dependent variable combination. Table 6 provides a summary of the ANOVA results for the central processing test-dependent variable combinations. For those combinations in which no differences were found between the rested days, it was assumed that post-sleep loss recovery performance was complete. Reliability analyses were then conducted on these variables to determine the appropriateness of combining data across the four rested testing sessions. Performance differences were found for five test-dependent variable combinations, including: Mathematical Processing-RT, Spatial Processing-RT, Grammatical Reasoning-RT, Memory Search (Mset=2)-PC, and Memory Search (Mset=4)-PC. For these combinations, trend analyses were conducted with each testing session treated independently (i.e., Rest Day1 vs. Rest Day2 vs. 18-Hr SD vs. 24-Hr SD vs. Rest Day 3 vs. Rest Day 4). It was hypothesized that trend analyses would assess underlying chronological effects (e.g., recovery effects, practice effects, etc.).

Reliability Between Rested Testing Sessions

In order to justify the combining of rested testing sessions together, a measure of reliability was calculated for all the perceptual and motor output test-dependent variable combinations, and the central processing combinations that failed to reach univariate significance (see Table 6). This measure of the reliability, or consistency between similar rested testing sessions was Cronbach's alpha coefficient (Cronbach, 1951). Cronbach's alpha is regarded as one of the most acceptable methods to assess reliability between different tests or testing sessions (Carmines and Zeller, 1979; Walsh and Betz, 1990).

According to Murphy and Davidshofer (1988), alpha values equal to or greater than 0.60 indicate a sufficient level of reliability for most testing situations. In the following

Table 6. Statistical summary table for the central processing test-dependent variable combinations for all rested testing sessions.

CENTRAL PROCESSING TEST/DEPENDENT VARIABLE COMBINATIONS	All Rest Days p-Value
REACTION TIME	
Memory Search (Mset = 2)	NS
Memory Search (Mset = 4)	NS
Mathematical Processing	<.05
Spatial Processing	<.001
Grammatical Reasoning	<.05
STANDARD DEVIATION	
Memory Search (Mset = 2)	NS
Memory Search (Mset = 4)	NS
Mathematical Processing	NS
Spatial Processing	NS
Grammatical Reasoning	NS
PERCENT CORRECT	
Memory Search (Mset = 2)	<.01
Memory Search (Mset = 4)	<.001
Mathematical Processing	NS
Spatial Processing	NS
Grammatical Reasoning	NS

analysis, a more conservative acceptance range of 0.65 or greater was used to insure maximum consistency between the rested testing sessions.

Table 7 lists the Cronbach's alpha values for each test-dependent variable combination across all four rested testing sessions. As indicated in Table 7, only three test-dependent variable combinations failed to reach the critical alpha level. These included: Spatial Processing-Percent Correct, Grammatical Reasoning-Percent Correct, and Reaction Time (Double Response)-Standard Deviation. Consequently, the aggregate combination of all four rest days was not used for these test-dependent variable combinations. In order to further analyze these test-dependent variable combinations, logical combinations of the rested days resulted in the following combinations: a "pre-sleep loss" rested day combination (Rest Day 1 and Rest Day 2), and a "post-sleep loss" rested day combination (Rest Day 3 and Rest Day 4).

Table 8 lists the Cronbach's alpha values obtained for these "pre-sleep loss" and "post-sleep loss" combinations of rested testing sessions. It is evident that only one additional test-dependent variable combination reached statistical significance, and furthermore, only under the pre-sleep loss combination. This test-dependent variable combination is the Reaction Time (Double Response)-Standard Deviation combination. Further analysis of this test-dependent variable combination was performed using the "pre-sleep loss" rested session.

Based on the results, only two test-dependent variable combinations failed to reach an acceptable level of consistency, or reliability between the rested testing sessions. These test-dependent variable combinations included Spatial Processing-Percent Correct and Grammatical Reasoning-Percent Correct. These combinations were not analyzed.

Table 7. Cronbach's alpha values for all test-dependent variable combinations across all four rested sessions.

TEST-DEPENDENT VARIABLE COMBINATION	ALPHA
Reaction Time (Basic) - Reaction Time	.9161
Reaction Time (Basic) - Standard Deviation	.8819
Reaction Time (Basic) - Percent Correct	.8816
Reaction Time (Coded) - Reaction Time	.7230
Reaction Time (Coded) - Standard Deviation	.8235
Reaction Time (Coded) - Percent Correct	.9050
Reaction Time (Time Uncertainty) - Reaction Time	.7679
Reaction Time (Time Uncertainty) - Std Deviation	.7996
Reaction Time (Time Uncertainty) - Percent Correct	.7879
Reaction Time (Double Response) - Reaction Time	.9779
Reaction Time (Double Response) - Std Deviation	.6140*
Reaction Time (Double Response) - Percent Correct	.9026
Reaction Time (Inversion) - Reaction Time	.8759
Reaction Time (Inversion) - Standard Deviation	.8313
Reaction Time (Inversion) - Percent Correct	.8470
Memory Search (Set = 2) - Reaction Time	.9433
Memory Search (Set = 2) - Standard Deviation	.8597
Memory Search (Set = 4) - Reaction Time	.8586
Memory Search (Set = 4) - Standard Deviation	.8190
Mathematical Processing - Standard Deviation	.7565
Mathematical Processing - Percent Correct	.6520
Spatial Processing - Standard Deviation	.8366
Spatial Processing - Percent Correct	.5851*
Grammatical Reasoning - Standard Deviation	.9071
Grammatical Reasoning - Percent Correct	.4437*
Unstable Tracking - Number of Resets	.6507
Unstable Tracking - RMS Error	.8057

* Alpha values not reaching a critical value of 0.65 or greater

Table 8. Cronbach's alpha values for all test-dependent variable combinations for the pre-sleep loss and post-sleep loss rested sessions.

TEST-DEPENDENT VARIABLE COMBINATION	Pre-Sleep Loss Alpha	Post-Sleep Loss Alpha
Reaction Time (Double Response) - Std Deviation	.8525	.3525*
Spatial Processing - Percent Correct	.4697*	.2645*
Grammatical Reasoning - Percent Correct	.1056*	.5982*

* Alpha values not reaching a critical value of 0.65 or greater

Based on the Cronbach's alpha values, combinations of the rested days were formed, and then one-way within groups univariate analyses of variance (ANOVAs) were used to test for performance differences between the combination of the rested days and each of the two sleep loss sessions (18-hours and 24-hours) on various dependent measures. For the Reaction Time, Memory Search, Mathematical Processing, Spatial Processing, and Grammatical Reasoning Tests, performance differences were analyzed using mean reaction time (mean RT), mean standard deviation of the reaction times (mean SD), and mean percentage correct (or response accuracy); analyses were based on the mean number of resets and the mean RMS error for the Unstable Tracking Test. The univariate ANOVA procedure is sufficiently robust to be relatively unaffected by minor deviations in normality, as is the case with the mean SDs and mean percent correct dependent measures (see Stevens, 1986, pp. 412-415 for a discussion of this issue).

Perceptual Tasks

The means for each dependent variable of the Reaction Time Test conditions (i.e., Basic, Coded, Time Uncertainty, Double Response, and Inversion) are reported in Appendix D for each rested session, the combination of the rested sessions, and the two sleep loss sessions. Also in Appendix D are graphs for each dependent variable of the Reaction Time Test conditions across all testing sessions. [Note: The two Basic conditions performed during each testing session have been averaged together for the following analyses]. Table 9 provides a summary of the Reaction Time Test conditions results at both the 18-hour and 24-hour levels of sleep loss. Those conditions that reached significance are described in greater detail below.

Table 9. Statistical summary table for the perceptual test/dependent variable combinations after 18-hour and 24-hour sleep loss.

PERCEPTUAL TEST/DEPENDENT VARIABLE COMBINATIONS	p-Value at 18-Hours	p-Value at 24-Hours
REACTION TIME		
Basic	NS	NS
Coded	NS	NS
Time Uncertainty	NS	NS
Double Response	NS	NS
Inversion	<.05	NS
STANDARD DEVIATION		
Basic	NS	<.01
Coded	NS	<.001
Time Uncertainty	NS	<.05
Double Response	NS	<.01
Inversion	NS	<.05
PERCENT CORRECT		
Basic	NS	<.05
Coded	NS	<.05
Time Uncertainty	NS	<.05
Double Response	NS	<.01
Inversion	NS	<.05

Reaction Time and Sleep Deprivation

In general, it appeared that the perceptual resource was affected very little by sleep deprivation with regard to average response speed. One-way within groups ANOVAs were performed on mean reaction time for the Basic, Coded, Time Uncertainty, Double Response, and Inversion conditions of the Reaction Time Test to determine if any significant differences existed between the combination of the rested days and the two sleep deprived sessions. The only significant effect of sleep loss on mean RT occurred for the Inversion condition after 18 hours without sleep (F (1,10) = 9.17, p < .05). It showed that subjects reacted more slowly under sleep deprivation (mean RT = 658.0 msec) than when they were rested (mean RT = 625.7 msec).

Standard Deviation and Sleep Deprivation

Overall, sleep deprivation, specifically after 24 hours, definitely impaired the consistency of speed at which subjects responded to perceptual stimuli. One-way within groups ANOVAs were performed on the mean reaction time standard deviations for the Basic, Coded, Time Uncertainty, Double Response, and Inversion conditions of the Reaction Time Test to determine if any significant differences occurred between the combination of the rested days and the two sleep deprived sessions. After 24 hours without sleep, significant main effects were found for all Reaction Time Test conditions.

The results of the Basic condition (F (1,10) = 12.24, p < .01) showed that subjects responded with greater variability under sleep deprivation (mean SD = 187.9 msec) than when they were rested (mean SD = 121.5 msec). Analogous results were obtained for each of the remaining conditions. The Coded condition (F (1,10) = 19.12, p < .001) demonstrated that subjects responded with more inconsistency to perceptually degraded stimuli under sleep deprivation (mean SD = 208.1 msec) than when they were rested (mean SD = 150.6 msec). The Time Uncertainty condition (F (1,10) = 7.26, p < .05) led to greater response variability to temporally uncertain visual stimuli under sleep deprivation (mean SD = 211.8 msec) than when they were rested (mean SD = 155.7 msec). The results of the Double Response condition (F (1,10) = 10.62, p < . 01) indicated that subjects responded with greater variability to increased task demands or loading while sleep deprived (mean SD = 237.7 msec) than when they were rested during the two days prior to the sleep loss sessions (mean SD = 138.3 msec). Finally, the Inversion condition (F (1,10) = 5.75, p < .05) showed that subjects responded less predictably to incompatible stimulus-response arrangements under sleep deprivation (mean SD = 209.5 msec) than when they were rested (mean SD = 172.7 msec).

Response Accuracy and Sleep Deprivation

Overall, the perceptual resource with regard to response accuracy was consistently degraded after 24 hours without sleep. For each of the Reaction Time Test conditions (i.e., Basic, Coded, Time Uncertainty, Double Response, and Inversion), one-way within groups ANOVAs were performed on the mean percentage correct to assess if any significant differences occurred between the combination of the rested days and the two sleep deprived sessions. As with the standard deviations, significant main effects on mean response accuracy were found for all Reaction Time Test conditions after 24 hours without sleep.

The results of the Basic condition (F (1,10) = 8.67, p < . 05) demonstrated that subjects responded less accurately under sleep deprivation (mean = 85.0 % correct) than when they were rested (mean = 94.9 % correct). Analogous results were obtained for each of the remaining conditions. The Coded condition (F (1,10) = 9.60, p < .05) demonstrated that subjects responded less accurately to perceptually degraded stimuli when they were sleep deprived (mean = 79.4 % correct) than when they were rested (mean = 89.4 % correct). The Time Uncertainty condition (F (1,10) = 5.53, $p < .05$) led to impaired response accuracy to temporally uncertain visual stimuli when subjects were sleep deprived (mean = 82.2 % correct) than when they were rested (mean = 88.8 % correct). The results of the Double Response condition (F (1, 10) = 11.04, $p < .01$) indicated that subjects responded with less accuracy to increased task demands or loading while sleep deprived (mean = 82.2 % correct) than when they were rested (i.e., across all four rested sessions) (mean = 91.7 % correct). Finally, the Inversion condition (F (1,10) = 5.16, $p < .05$) showed that subjects responded less accurately to incompatible stimulus-response arrangements when they were sleep deprived (mean = 76.0 % correct) than when they were rested (mean = 84.1 % correct).

Central Processing Tasks

The means for each dependent variable of the Memory Search (Mset sizes of 2 and 4), Mathematical Processing, Spatial Processing, and Grammatical Reasoning Tests are provided in Appendix E for each rested session, the combination of rested sessions, and the two sleep loss sessions. Also in Appendix E are the graphs for each dependent variable of the central processing tests across all testing sessions.

Reaction Time and Sleep Deprivation

Univariate ANOVAs. In general, the central processing resource was only mildly affected by sleep deprivation with respect to response time. One-way within groups ANOVAs were performed on the mean reaction time for the Memory Search Tests (Mset = 2 and 4) to determine if any significant differences existed between the combination of

Table 10. Statistical summary table for the central processing test/dependent variable combinations after 18-hour and 24-hour sleep loss.

CENTRAL PROCESSING TEST/DEPENDENT VARIABLE COMBINATION	p-Value at 18-Hours	p-Value at 24-Hours
REACTION TIME		
Memory Search (Mset = 2)	NS *	<.05
Memory Search (Mset = 4)	NS	NS
STANDARD DEVIATION		
Memory Search (Mset = 2)	<.05	<.01
Memory Search (Mset = 4)	NS	<.05
Mathematical Processing	NS	NS
Spatial Processing	NS	NS
Grammatical Reasoning	NS	<.05
PERCENT CORRECT		
Mathematical Processing	NS	NS
Spatial Processing	-	-
Grammatical Reasoning	-	-

* $p = .060$

rested days and the two sleep loss sessions. Table 10 provides a summary of the statistical results for these tests at both the 18-hour and 24-hour levels of sleep loss. The only significant main effect of sleep loss on mean RT occurred for the Memory Search (Mset = 2) Test (F (1,10) = 6.69, $p < .05$) after 24 hours without sleep. The results of the Memory Search (Mset = 2) Test demonstrated that the speed of recognition was slower when subjects were sleep deprived (mean RT = 540.2 msec) than when they were rested (mean RT = 502.3 msec). Surprisingly, the speed of recognition was only impaired for the less challenging and cognitively complex task that required subjects to memorize a set of two letters.

After 18 hours of sleep loss, mean RT was slightly degraded for the Memory Search (Mset = 2) Test, just failing to reach a level of statistical significance (F (1,10) = 4.49, p = 0.060). It is reported due to its importance for further discussion. Examination of the means indicated that subjects tended to respond more slowly when they were sleep deprived (mean RT = 565.5 msec) than when they were rested (mean RT = 502.3 msec).

Trend Analyses. Trend analyses were performed on mean RT for the Mathematical Processing, Spatial Processing, and Grammatical Reasoning Tests to determine if there were any chronological trends across the six testing sessions. A statistical summary of the trend analyses are reported in Table 11. Significant linear trends were obtained for the Mathematical Processing Test (F (1,10) = 5.38, $p < .05$) and Spatial Processing Test (F (1,10) = 14.61, $p < .01$), both demonstrating that mean RT decreased across the testing sessions. A significant cubic trend was obtained for the Grammatical Reasoning Test (F (1,10) = 14.17, $p < .01$). The performance data indicated that initially mean RT decreased between Rest Day 1 and Rest Day 2, then increased after both the 18-hr and 24-hr sleep loss sessions, and then decreased again on Rest Days 3 and 4. The three trends are graphically portrayed in Appendix E.

Table 11. Statistical summary table for the central processing test/dependent variable combination trend analyses.

CENTRAL PROCESSING TEST/ DEPENDENT VARIABLE COMBINATION	**Trend Obtained (p-Value)**
REACTION TIME	
Mathematical Processing	Linear (<.05)
Spatial Processing	Linear (<.01)
Grammatical Reasoning	Cubic (<.01)
PERCENT CORRECT	
Memory Search (Mset = 2)	Quadratic (<.01)
Memory Search (Mset = 4)	Cubic (<.05)

Standard Deviation and Sleep Deprivation

Similar to the effects of sleep loss on response speed, the variability of response speed was only mildly affected by sleep loss for the central processing tests. For each of the central processing tests (i.e., Memory Search, Mathematical Processing, Spatial Processing, and Grammatical Reasoning), one-way within groups ANOVAs were performed on the mean standard deviations (mean SD) of the reaction times to assess if any significant differences occurred between the combination of the rested days and the two sleep deprived sessions. Table 10 provides a summary of the statistical results for these tests at both the 18-hour and 24-hour levels of sleep loss. Significant main effects were found for the Memory Search (Mset = 2 and 4) Tests and the Grammatical Reasoning Test.

Significant main effects of sleep loss on mean SD occurred for the Memory Search (Mset = 2) Test occurred after 18 hours without sleep (F (1,10) = 5.29, $p < .05$), and after 24 hours (F (1,10) = 11.20, $p < .01$). After 18 hours without sleep, subjects responded with greater variability (mean SD = 162.0 msec) than when they were rested (mean SD = 103.4 msec), and the degree of variability grew even stronger after 24 hours without sleep (mean SD = 182.7 msec). A significant effect of sleep loss on mean SD for the Memory Search (Mset = 4) Test was found after 24-hour sleep deprivation (F (1,10) = 9.52, $p < .05$), which showed that subjects responded more inconsistently while sleep deprived (mean SD = 200.3 msec) than when rested (mean SD = 103.2 msec).

The Grammatical Reasoning Test resulted in a significant effect of sleep loss on mean SD after 24 hours without sleep (F (1,10) = 6.26, $p < .05$). It showed that subjects also responded with greater variability to logical reasoning activities under sleep deprivation (mean SD = 1531.0 msec) than when they were rested (mean SD = 1287.6 msec).

Response Accuracy and Sleep Deprivation

Univariate ANOVAs. Overall, the results indicated that response accuracy for central processing tests was unaffected by sleep loss. One-way within groups ANOVAs were performed on the mean percent correct for the Mathematical Processing Test to determine if any significant differences existed between the combination of rested days and the two sleep loss sessions. Table 10 provides a summary of the statistical results for the Mathematical Processing Test at both the 18-hour and 24-hour levels of sleep loss. No statistically significant effects was found.

Trend Analyses. Trend analyses were performed on mean percent correct for the Memory Search Test conditions (Mset = 2 and 4) to determine if there were any chronological trends across the six testing sessions. A statistical summary for the trend analyses are reported in Table 11. A significant quadratic trend was obtained for the Mset = 2 condition (F (1,10) = 12.23, $p < .01$) indicating significant recovery performance on Rest Days 3 and 4. A significant cubic trend was obtained for the Mset = 4 condition (F (1,10) = 6.29, $p < .05$). The performance data indicated that mean percent correct decreased linearly across Rest Day 1, Rest Day 2, and the two sleep loss sessions; then increased on Rest Day 3; and finally decreased on Rest Day 4. These trends are graphically portrayed in Appendix E.

Motor Output Task

The means for each of the Unstable Tracking Test dependent variables are presented in Appendix F for all the rested days, and both sleep loss sessions. Also in Appendix F are the graphs for both dependent variables of the Unstable Tracking Test across all testing sessions. Table 12 provides a summary of the statistical results for the Unstable Tracking

Test at both the 18-hour and 24-hour levels of sleep loss. Those conditions that reached significance are described in greater detail below. In general, the maintenance of stable and accurate motor performance was definitely affected by one night's sleep loss.

Number of Resets and Sleep Deprivation

A one-way within group ANOVA was performed on the mean number of resets for the Unstable Tracking Test to determine if any significant difference between the rested sessions and the two sleep loss sessions. No significant decrements were found at either level of sleep deprivation.

RMS Error and Sleep Deprivation

A one-way within group ANOVA was also performed on the mean RMS error for the Unstable Tracking Test to determine if any significant difference between the rested sessions and the two sleep loss sessions. A significant effect of sleep loss occurred after 24 hours without sleep (F (1,10) = 10.85, $p < .01$). It showed that subjects had greater difficulty maintaining the cursor position on the central target area while sleep deprived (mean RMS Error = 209.2) than when they were rested (mean RMS Error = 73.3).

Table 12. Statistical summary table for the motor output test/dependent variable combinations after 18-hour and 24-hour sleep loss.

MOTOR OUTPUT TASK/DEPENDENT VARIABLE COMBINATION	p-Value at 18-Hours	p-Value at 24-Hours
NUMBER OF RESETS		
Unstable Tracking	NS	NS
RMS ERROR		
Unstable Tracking	NS	<.01

CHAPTER IV

DISCUSSION

An analysis of one night's sleep deprivation literature indicated ambiguous performance results, whereas performance-based research following more than one night's sleep loss positively demonstrated information processing degradations. It was argued that some of the ambiguity in previous research studies can be attributed to a lack of standardization in the tests that were employed, and a variety of methodological problems. It was hypothesized that the effects of one night's sleep loss on various information processing resources would be more effectively examined using an accepted, standardized, and experimentally validated test battery, the NATO/AGARD STRES Battery.

The effect of one night's sleep loss on the perceptual resource, examined using Reaction Time Tests, indicated that erratic and unpredictable fluctuations in response speed are likely to occur, often without any overall increases in response time. There are also strong indications that increased probabilities of error can result.

The sleep loss effects on the central processing resource still appear to be ambiguous, but there is evidence that degradations may or may not occur depending on the degree to which working memory is aroused by a particular activity or test. It is believed that the lowered level of arousal produced by sleep loss may have resulted in especially poorer performance for very difficult (e.g., Grammatical Reasoning) and very easy (e.g., Memory Search) tasks, whereas performance was better for moderately demanding and complex tasks (e.g., Spatial and Mathematical Processing). Overall, the results on the central processing tests in this study indicated that only two of the tests, the Memory Search and Grammatical Reasoning, produced degraded performance after sleep loss. In these cases, only response speed and the standard deviation of response speed were impaired, while no significant decrements in accuracy were identified.

Finally, the effects of sleep loss on the Unstable Tracking Test, lends support to the fact that the maintenance of stable and accurate motor performance is impaired after only one night without sleep.

Perceptual Task and Sleep Deprivation

It is evident from the literature review that the results obtained from previous sleep deprivation studies using perceptually based tasks, such as reaction time tests and vigilance tests, have yielded equivocal findings (e.g., Wilkinson, 1959; Wilkinson, 1961; Glenville, Broughton, Wing, and Wilkinson, 1978; Frowein, Reitsma, and Aquarius, 1981; Sanders, Wijnen, and Arkel, 1982; and Steyvers, 1987). Generally speaking, it appeared that some of these studies demonstrated that vigilance tasks led to significant decrements in response speed and increased occurrences of response "lapses" (Williams, Lubin, and Goodnow, 1959), however, many of these same studies failed to detect decrements in response accuracy.

The results of this study clearly indicated that performance during the two rested testing sessions following the sleep deprivation period (i.e., recovery performance) achieved an acceptable level of performance matching the performance obtained during the two rest days preceding sleep loss. Meddis (1982) argued that additional testing should be conducted on subjects after they have recovered from the sleep deprivation ordeal -

particularly in repeated measures studies. Meddis cites the lack of examining recovery performance as a common methodological problem that has plagued sleep deprivation research over the years. His argument maintained that, "...any return to baseline performance levels can be used as proof that performance decrements during the sleep deprivation period were, in fact, caused by a lack of sleep" (pp. 232-233). Thus, the perceptually based performance decrements obtained in the present study can be confidently attributed to the effects of sleep deprivation.

Contrary to previous experimental findings, only one of the Reaction Time Test conditions in the STRES Battery, specifically, the Inversion condition, demonstrated a significant impairment in response speed. Interestingly enough, this decrement occurred after only 18 hours of sleep deprivation, and did not reoccur after 24 hours of sleep loss. There are several reasons why decrements in reaction time may not have occurred in most of the other Reaction Time Test conditions. These include: (1) short task duration; (2) lack of task difficulty; and (3) superior task proficiency.

It has been frequently noted that tasks of short duration do not provide sufficient time for the "true" effects of sleep deprivation to manifest themselves, or as Johnson (1982) stated, "...the longer the task, the more sensitive it is to total sleep deprivation" (p. 121). It is believed that a sleep deprived subject can pull himself/herself together, expend just enough extra effort, and perform normally for a few minutes. But, with longer tasks, and after extended periods of sleep loss, the basic sleep loss deficit will eventually reveal itself. For example, Williams, Lubin, and Goodnow (1959) were able to reveal significant decrements in a vigilance task after only 2 min following 70 hours of sleep loss. Williams (1961, 1965) was not able to demonstrate any appreciable performance decrements in 5-choice test of serial reaction, a vigilance task, and an addition task in the first 5 min following 24 hours of sleep loss, but significant impairments were found following 15-min versions of the same tasks. Similar findings have been found using the Wilkinson Addition Test (Donnell, 1969). It might be the case in this study that the durations for the various reaction time task conditions need to be extended in order to assess the actual effects of one night's sleep loss. Based on previous studies, it appears that at least 10-15 min of time-on-task (TOT) is required to assess performance in 24-hour sleep loss studies, and only 2-5 min TOT is required for extended sleep deprivation experiments (e.g., 48 or more hours of sleep loss). Although the cumulative TOT for the STRES Battery's Reaction Time Task was 15 min, the actual TOT for each condition of the Reaction Time Task (e.g., Basic, Coded, Time Uncertainty, etc.) was only 3 min. Furthermore, in this particular study, each 3-min condition was performed independently, and was separated in time by approximate 3-min periods during which subjects were responding to the NASA TLX workload rating scale (see pp. 47-48). Thus, the collection of NASA TLX data may have provided a "recovery period" which suppressed the underlying fatigue effects.

Johnson (1982), also in his overview of sleep loss task variables, raised and discussed the impact of task difficulty. He mentioned that "performance on difficult tasks is more sensitive to sleep loss" (p. 121). Johnson referred to a study by Williams and Lubin (1967) where changes of difficulty in an addition task produced differences in significance. In their study, no significant effects were discovered at a mental addition rate of one addition per 2 sec, however, significant decrements were detected when the rate of addition was increased to one addition every 1.25 sec. In the present study, it may be the case that the Reaction Time Test conditions were relatively easy to perform, and were not sensitive to the potentially degrading effects of sleep loss. Since the Inversion condition was considered by subjects as the most difficult Reaction Time Test condition (as reported informally), it seems reasonable that the Inversion condition was the only task that resulted in significant response time decrements.

The difficulty of a task is closely related to the level of proficiency a subject may develop for a particular task, or a set of tasks. In this study the subjects were very well practiced on the STRES Battery tests, and in particular the Reaction Time Tests. In total, the subjects performed 16 practice trials of the Basic condition, and 4 practice trials of the Coded, Time Uncertainty, Double Response, and Inversion conditions, respectively. It is hypothesized that extensive practice may have led to an "automatization" of task performance (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Since subjects became so well-practiced on the Reaction Time Tests, the true effects of the sleep deprivation were not realized as the subjects became essentially "immune" to its effects. Immunization, as it relates to the field of medicine, might be analogously related to the study of sleep deprivation, in that the subjects developed sufficient (if not excessive) levels of practice to ward off the deleterious effects of sleep loss, as do patients who develop sufficient levels of antibodies to ward off the onset of diseases.

Perhaps the most interesting of the findings reported in this study comes from the analyses of the response time standard deviations. After 24 hours of sleep deprivation, all of the Reaction Time Test conditions led to significant increases in variability; no significant changes were found after 18 hours of sleep deprivation. No previous studies have been identified that statistically compared response time standard deviations between rested and sleep deprived sessions. However, an investigation of standard deviations is closely related to a phenomenon, known as the "lapse hypothesis", which has been extensively examined in many sleep deprivation experiments (e.g., Williams, Lubin, and Goodnow, 1959; Williams, 1961, Lubin, 1967, Kjellberg, 1977, and Johnson, 1982).

Basically, the lapse hypothesis states that a performance decrement is the result of involuntary, intermittent periods of lowered reactive capacity. The hypothesis assumes that as sleep loss increases, so do the frequency and the duration of the lapses. For the lapse hypothesis, an important aspect of the task is whether it is self-paced or work-paced (i.e., "experimenter-paced"). In self-paced reaction time tasks, where stimuli are presented until the subject responds, the lapse hypothesis predicts that response times will lengthen, and should become increasingly positively skewed with increased sleep deprivation. Since the standard deviation of the response time is positively correlated with the degree of skew, it is expected that standard deviations will be larger after sleep loss. In contrast, in a work-paced task, where stimuli are presented for only a limited amount of time, the lapse hypothesis predicts decrements in accuracy. Since the Reaction Time Tests used in this study are considered work-paced, the lapse hypothesis would predict significant impairments in accuracy measures, with no, or very few decrements in response time. In fact this was the case, as all conditions produced significant impairments in accuracy following 24 hours of sleep loss, and only the Inversion condition produced significant response time decrements (again, probably the result of high task difficulty).

As Lubin (1967) noted, the basic postulate of the lapse hypothesis is that acute sleep loss causes mental and motor lapses. Between lapses, the subject may perform normally. Williams, Lubin, and Goodnow (1959) demonstrated this point clearly using a 2-choice reaction time test, with 72 trials in each test session. The average of the ten shortest reaction times changed very little, even after 72 hours of sleep loss. But the average of the ten longest reaction times in each session expanded quickly to four times the baseline level. Thus, as sleep loss increases, performance became more and more uneven, with efficient behavior alternating with faltering responses or no responses at all. The authors concluded that the mean or median response time was not a sensitive measure of this unevenness.

The response time standard deviation, which measures the dispersion (or variability) of response times relative to the mean, provides an effective and sensitive measure of any uneven or erratic responding behavior. The results of this study clearly indicate that the response time variability significantly differed between the rested sessions and the 24-hour sleep deprivation session for the Basic, Coded, Time Uncertainty, Double Response, and Inversion conditions. These effects clearly demonstrate a lack of consistency in the subject's capability to respond quickly to visual stimuli following one night's sleep deprivation. After sleep deprivation, subjects appear to have difficulty maintaining a consistent level of performance, and have essentially become erratic operators. In essence, these results indicate that human performance can become unpredictable after only 24 hours of sleep loss. The impact of reduced predictability and reliability of performance after one night's sleep loss will have significant implications in the design of complex systems, which involve any monitoring and vigilance activities.

As previously mentioned, all the Reaction Time Test conditions also produced significant impairments in response accuracy following 24 hours or sleep loss, but again, no significant differences were noticed after 18 hours. Consistent with predictions based on the lapse hypothesis, all the "work-paced" Reaction Time Test conditions resulted in decrements in response accuracy. In a work-paced task, it is hypothesized that when a subject is affected by a lapse, he or she will either fail to respond within the allowable time resulting in an error of omission, or will miss the stimuli completely (thus resulting in an incorrect response).

The present findings are consistent with those of Steyvers (1987) and Sanders, Wijnen, and van Arkel (1982). Steyvers (1987) found significant increases in the proportions of errors after 32 hours of sleep deprivation for both a Degraded and a Non-Degraded reaction time task. These tasks are very similar to the Coded and Basic conditions used in the STRES Battery. Sanders, Wijnen, and van Arkel (1982) used a Signal Degradation and a S-R Compatibility 4-choice reaction time task after one night's sleep loss, and found significant decrements in the percentages of errors and missed trials. The Signal Degradation task used by Sanders, Wijnen, and van Arkel is nearly identical to the STRES Battery's Coded condition. The results obtained in this study provide a strong replication of these findings.

The present findings complement several other studies, which could all be classified as self-paced tasks (e.g., Wilkinson, 1959, Wilkinson, 1961, Glenville, Broughton, Wing, and Wilkinson, 1978; Frowein, Reitsma, and Aquarius, 1981; and Farmer and Green, 1985). Interestingly, the results of these studies also correspond with lapse hypothesis predictions, that is, self-paced tasks will lead to decrements in speed, but high accuracy rates. It is assumed that when a subject experiences a lapse, he/she will be non responsive until the lapse is over (thereby increasing reaction time), yet the correct response may nevertheless occur.

The results of this experiment demonstrated a classic "speed-accuracy tradeoff" following sleep deprivation, where overall mean RT remained sufficiently quick and overall mean response accuracy became degraded. Although subjects were repeatedly instructed to respond both quickly and accurately, it was evident that subjects could not maintain successful performance on both. Subsequently, subjects traded off response accuracy in an effort to maintain acceptable levels of response speed.

Overall, the present findings failed to replicate the consensus of studies that have found decrements in response speed for perceptual, vigilance-type tasks. However, as noted above, there are several methodological reasons (e.g., task duration, difficulty, and proficiency) associated with the particular procedure for this study, and the design of the STRES Battery tests that may have missed some potential sleep loss impairments. Nevertheless, strong findings were found for the response time standard deviations, which demonstrated very erratic and unpredictable response behavior following sleep deprivation. Significant decrements in response accuracy were also found for all the perceptual conditions. In summary, the current findings in light of previous findings, indicate that perceptual, work-paced tasks will result in erratic fluctuations of response speed, perhaps with no overall increases in speed, and increased probabilities of error.

Central Processing Tasks and Sleep Deprivation

The central processing resource, as described by Eggemeier (1988), differentiates three processing functions: a) information manipulation or transformation; b) reasoning activities using relational rules; and c) planning and scheduling activities. Each of these functions are represented and utilized in the Mathematical Processing, Memory Search, Spatial Processing, and Grammatical Reasoning Tests of the STRES Battery. Overall, the results of this study indicate that only two of these tests, the Memory Search and Grammatical Reasoning Tests, were adversely impaired by the effects of one night's sleep loss. More specifically, only response speed and variability (as measured by response speed standard deviations) were affected, whereas no significant decrements in accuracy were observed. In general, an explanation of the effects of sleep loss on central processing task performance tends to be less straightforward than that of the perceptual and motor output tasks.

The results of the statistical analyses indicated that 5 of the 15 central processing test-dependent variable combinations failed to reach an acceptable level of post-sleep loss recovery performance. They include: Mathematical Processing-RT, Spatial Processing-RT, Grammatical Reasoning-RT, Memory Search (Mset = 2)-PC, and Memory Search (Mset = 4)-PC. To understand what occurred for these combinations, we must closely examine the trend analyses. The linear trends obtained for the Mathematical Processing-RT and Spatial Processing-RT combinations indicated that learning or practice effects may still be occurring for these tests. The cubic trend for the Grammatical Reasoning-RT combination is more difficult to explain. A closer examination of the data and graph (see Appendix E) demonstrated that with the exception of Rest Day 1, the performance data were impaired as a result of sleep deprivation. It is suggested that the novelty of the first experimental session (e.g., physiological data collection) may have led to the spuriously large mean RT for Rest Day 1. The quadratic trend acquired for the Memory Search (Mset = 2)-PC combination indicated that recovery performance closely approximated baseline performance, but failed to reach to an acceptably high performance level. Performance differences across the four rested days appear to be caused by Rest Day 3, which failed to reach the exceptionally high accuracy levels attained for Rest Days 1, 2, and 3. Similar to the Grammatical Reasoning-RT combination, the Memory Search (Mset = 4)-PC combination resulted in a cubic trend. An in-depth examination of the data and graph suggested that with the exception of Rest Day 4, response accuracy appeared to be impaired as a result of sleep loss. It is hypothesized that the unexpected decrease in mean response accuracy on Rest Day 4 are the result of motivational problems associated with the final day of testing.

The other 10 central processing test-dependent variable combinations achieved an acceptable level of recovery performance, and thus recovery was considered complete. Performance decrements obtained for these combinations can be confidently attributed to the effects of sleep deprivation.

A wide variety of memory recall and recognition tests have been used in previous sleep deprivation studies (e.g., Williams, Geisking, and Lubin, 1966; Elkin and Murray, 1974; Polzella, 1975; Glenville, Broughton, Wing, and Wilkinson, 1978; and Schlegel, Gilliland, and Schlegel, 1986), and therefore it is very difficult to compare and contrast the findings. Only Schlegel, Gilliland, and Schlegel (1986) utilized a Sternberg memory search test, which included the levels used in the STRES Battery. They found significant increases in response times for all three levels of task difficulty, and found little accompanying decrements in response accuracy. These findings are generally congruent with the present study, with the exception of the Memory Search condition Mset = 4, whose reaction time measures were not significantly impaired. This particular finding, however, is consistent with Polzella (1975), who found no overall effect of reaction time for a short-term recognition memory test.

An analysis of the Memory Search response time standard deviations showed that the speed of recognition memory became unpredictable and more erratic under sleep loss. The erratic behavior was evident under both the easy (Mset = 2) and more difficult (Mset = 4) versions of the memory test, but more dramatically impaired with the less difficult test as it was affected after both 18 and 24 hours of sleep loss.

As for the Grammatical Reasoning Test, the mean standard deviations were significantly higher after 24 hours without sleep. Once again, this demonstrates the unpredictability and inconsistency in performance resulting from as little as one night's sleep loss.

The present study found no significant impairments in the variability of response speed for both the Mathematical Processing and Spatial Processing Tests following 18 and 24 hours of sleep loss. It can only be assumed that the STRES Battery's version of the Mathematical Processing and Spatial Processing Tests were optimally challenging, and did not fall prey to the deleterious effects of sleep loss. No significant decrements in response accuracy were found for the Mathematical Processing Test after 18 and 24 hours of sleep loss. The maintenance of high accuracy levels is congruent with many previous studies (e.g., Loveland and Williams, 1963; Williams and Lubin, 1967; Donnell, 1969; and Schlegel, Gilliland, and Schlegel, 1986). Based on these results, one can confidently state that the likelihood of mathematical errors following sleep deprivation is very low, and the variability in response speed to mathematical problems appears to be unaffected by sleep loss.

As noted in the literature review, only Schlegel, Gilliland, and Schlegel (1986) have studied the effect of one night's sleep loss using a spatial processing test, and one which is very similar to that used in the STRES Battery. Consistent with their findings, the current study failed to yield any significant decrements in response accuracy and the variability of response speed. These findings provide a strong replication of the Schlegel, Gilliland, and Schlegel (1986) findings. As with the Mathematical Processing Test, it is believed that the Spatial Processing Test provides an optimal cognitive challenge, and subsequently delayed/deferred the onset of poorer performance caused by sleep loss.

The results of the central processing tasks indicate that only the Memory Search and Grammatical Reasoning Tests were adversely impaired by the effects of one night's sleep loss. More specifically, only performance in terms of their response speed and the variability of this speed were affected, whereas no significant decrements in accuracy rates were realized. At first glance, an explanation for these rather ambiguous results seems to be difficult to resolve. An obvious question exists: Why are some central processing tasks affected by sleep loss, while others are not ?

The answer to this question may lie in an interesting conclusion drawn by Farmer and Green (1985). Their conclusion was made after they discovered that performance on relatively simple, central processing laboratory tasks, such as continuous serial reactions, were disrupted to a greater extent by sleep loss than more difficult tasks that challenged a subject's logical and reasoning mental capacities. They suggested that such findings may be consistent with the principal of the Yerkes-Dodson Law, in that the optimal level of arousal is inversely related to task difficulty. The Law would predict that the lowered level of arousal produced by sleep loss may result in especially poorer performance for very easy and very difficult tasks, whereas performance may be better for moderately demanding and complex tasks. Hockey (1979) supports this contention by arguing that the difficulty of a task is based more on the degree to which it actively requires working memory, rather than the rapid input-output of information with minimal information storage.

The findings for the Battery's central processing tasks are much better understood when one views them in light of the Yerkes-Dodson Law. In this case, it appeared that tests that involved higher levels of cognitive activities, particularly the processing of linguistic materials, were more degraded by the effects of sleep deprivation. It is believed that the Memory Search Test, especially at the less difficult level (Mset = 2), was relatively easy, resulted in overall quick responses, and did not produce an adequate cognitive challenge for the subjects to ward off the deleterious effects of sleep loss. The more challenging Memory Search condition (Mset = 4) fared somewhat better under sleep loss, only resulting in significant decrements in response time standard deviations after 24 hours without sleep. On the other hand, the Grammatical Reasoning Test, perhaps the single most difficult test as reported by subjects, must have been difficult to perform after one night's sleep loss as response times become very erratic, and in general, much longer than any of the other central processing tests.

The results of this experiment also demonstrated a "speed-accuracy tradeoff" following sleep deprivation for the central processing tests. Contrary to the results obtained for the perceptual tests, subjects traded off overall mean RT on the central processing tests in an effort to maintain acceptable levels of response accuracy. Although subjects were continuously instructed to respond both quickly and accurately, it was evident that subjects could not maintain successful performance on both.

In summary, there are a variety of performance tests used to assess the central processing resource, for example, recognition memory tests, mental arithmetic, spatial processing tests, and grammatical and logical reasoning tests. Each of these tests, to a certain extent, will invoke working memory to process stimulus inputs into response outputs. The influence of one night's sleep loss, as it occurred in this study, is assumed to lead to a period of lowered arousal (Lisper and Kjellberg, 1972; Kjellberg, 1977). Human performance on central processing tests will either degrade or remain stable, depending on the degree to which working memory is aroused by a particular test. There appears to be a curvilinear relationship between the degree to which working memory is aroused and an individual's subsequent performance on that particular task. It appears that when demands on working memory are either very high or very low, the performance decrements of sleep deprivation are more noticeable. However, when the demands on working memory are moderate, task performance remained stable under sleep deprivation. For example, the Memory Search Tests, particularly the Mset = 2 condition which failed to arouse the sleep deprived subjects resulted in degraded performance (e.g., increased and inconsistent response speeds). Similarly, the most difficult test, the Grammatical Processing Test was highly arousing and very demanding. It too resulted in degraded performance as demonstrated by inconsistent response speeds. The Mathematical Processing and Spatial Processing Tests appear to have been moderately/optimally arousing activities, and resulted in stable performance following sleep loss.

Motor Output Task and Sleep Deprivation

The Unstable Tracking RMS error increased following sleep deprivation, but only after 24 hours without sleep. This finding is consistent with Schlegel, Gilliland, and Schlegel (1986), who found that the absolute mean tracking error of an unstable tracking task was adversely impaired by one night's sleep loss; and is also consistent with Farmer and Green (1985), who found significant decrements in RMS error on a two-axis compensatory tracking task after a single night of sleep loss. The current results provide a replication of the Schlegel, Gilliland, and Schlegel (1986) findings, as the STRES Battery's version of the Unstable Tracking Test is the same as the tracking task used in their study.

However, the findings of this study are inconsistent with those of Schlegel, Gilliland, and Schlegel (1986) with respect to the number of edge violations, or number of resets. Schlegel, Gilliland, and Schlegel (1986) found significant increases in the number of edge violations for all three levels of their unstable tracking task, however, the STRES Battery's Unstable Tracking Test was not adversely impacted. It is believed that key differences existed between the types of cursor control devices used in the present study (i.e., a joystick) and the Schlegel, Gilliland, and Schlegel (1986) study (i.e., a rotational control knob). Previous studies have clearly demonstrated that performance differences exist between different cursor control devices (Zeigler and Chernikoff, 1968; and Albert, 1982).

The results of this study clearly indicate that recovery performance achieved an acceptable level of performance matching the performance obtained during the two rest days preceding sleep loss. The motor output performance decrements obtained in this study can be confidently attributed to the effects of sleep deprivation.

Although very little research has been conducted on motor tracking behavior following sleep deprivation, and even less research using unstable tracking tasks, the present findings lend support to the fact that the maintenance of stable and accurate motor performance is definitely affected by only one night without sleep. This also lends support to the contention that performance on relatively simple and vigilant-like laboratory tasks, such the Unstable Tracking Test and the Reaction Time Tests, may be more adversely affected by one night's sleep loss than more complex and challenging tasks that help to maintain a subject's attentional and arousal levels.

Future Research

This is one of the first experimental studies in which the NATO/AGARD STRES Battery has been applied to study the effects of a stressor, in this case one night's sleep loss. In the present investigation, the performance effects of sleep deprivation was studied in a very controlled environmental setting. The use of this validated test battery should be applied to more realistic settings, such as process control operations (e.g., nuclear power plants, manufacturing plants, etc.), long-haul transportation industries (including air, ground, and sea transport), and other continuous and sustained operations, including medical emergency rooms and combat/military operations. The STRES Battery can be administered on a portable personal computer, which would facilitate its use in many applied research settings.

Since only male subjects were used in the present study, the results can only be generalized to that subset of the population. Follow-on studies, in both laboratory and applied settings, should include females in the subject pool. Because females have become a more significant part of the workforce, the effects of sleep deprivation on their performance needs to be investigated. Based on the author's literature review, no research on gender differences and sleep deprivation has been conducted. Similarly, investigating the impact of sleep loss on older individuals (50 years or older) will be important as the mean age of the working population continues to grow older (Myer, 1985).

It was noted in the discussion of the Reaction Time Test results that the lack of significant decrements in response speed might not have been noticed because of the short task duration (i.e., 3 min per test condition). The effect of time on task (TOT) after 24-hour sleep deprivation should be investigated by varying the lengths of the Reaction Time Test conditions, if not all the STRES Battery tests. The TOT durations could be experimentally manipulated in an effort to determine the "temporal threshold " at which sleep deprivation impairments begin to occur. The results of such a study would be extremely important not only in terms of developing better sleep deprivation research methodologies, but also in understanding the impact of sleep loss on tasks that require continuous monitoring and/or control activities.

Implications for Design

Several implications for the design of person-machine systems and jobs can be drawn from the results of the current study. The results demonstrated that performance on each information processing resource, that is, perception, central processing (cognition/decision making), and motor output, are affected to a certain extent by only one night without sleep.

For jobs and tasks that primarily involve significant amounts of visual monitoring or vigilance activities, a system designer must be aware that as little as 24 hours without sleep can result in radical fluctuations in the time required for operators to respond. If sleep loss cannot be avoided, the designer of such systems as process control workstations, security monitoring systems, or anesthesiology monitors, must ensure that important display elements are made very salient to the operator. Even though operators may respond to visual stimuli quickly overall, this research indicates that operators may have extreme difficulty in maintaining a consistent level of speed. The present findings also indicate that operators are susceptible to increased error-producing behavior in vigilance tasks after sleep loss.

Tasks that require a certain amount of cognitive processing, such as decision making, reasoning ability, or mental processing tend to be dependent on the degree to which working memory is aroused by a particular task. Very complex and cognitively challenging jobs, such military command and control functions or fault diagnosis in process control operations, appear to be too difficult to perform following sleep loss. In addition, performance on very easy and routine cognitive tasks tend to be degraded following sleep loss. Apparently, these less challenging tasks fail to arouse operators, which is compounded by the lowered level of arousal produced by sleep deprivation. Performance impairments on these cognitive tasks reside primarily in response speed and consistency of response speed. Optimally challenging tasks, such as mathematical calculations, graphical comprehension, and display reading, are relatively unaffected by one night's sleep loss.

Motor output, or specifically tracking performance is definitely impaired by only one night without sleep. This study demonstrated that the maintenance of stable and accurate motor performance became degraded. Assessments of long-haul truck driver tracking performance could provide indications of when driving abilities will become degraded. Not until drivers had received sufficient recovery sleep should they be allowed to continue traveling.

Overall, recovery from 24-hour sleep deprivation will be complete with as little as one night with normal amounts of sleep. Sleep loss recovery tends to be more complete for jobs that require use of the perceptual and motor output resources, and tends to be less complete for tasks requiring central processing operations. In addition, if a job is anticipated to include tasks where speed or accuracy are crucial to overall system performance and safety, system designers should be cautioned that sleep deprivation can lead operator "speed-accuracy tradeoffs". For perceptual tasks, overall response speed tends to be maintained with tradeoffs in response accuracy. For central processing tasks, response accuracy is maintained, while overall response speed is sacrificed.

As author, Martin Moore-Ede, so appropriately titled his book, *The Twenty-Four Hour Society* (1993), it is clear that many of recent years' person-machine tragedies and disasters (e.g., Exxon Valdez oil spill, Three Mile Island and Chernobyl nuclear accidents, and even the Challenger explosion) can be commonly linked together because the human component in the system was sleep deprived. The core of this modern problem is that technological innovation is competing with people; and the people are losing. Competitive pressures across industry and the impact of a global economy have forced people to operate 24 hours a day. It is important for designers to understand this human limitation to sleep loss in the design of person-machine environments.

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APPENDIX A

Food and Sleep Diary

Name:______________________________

FOOD AND SLEEP DIARY

DAY:____________________________ Time When You Awake:_______________

Breakfast (Y or N)____

____

____________________________Time:______________________

Morning Snack (Y or N)____________________________________

____

____________________________Time:______________________

Lunch (Y or N)____

____

____________________________Time:______________________

Afternoon Snack (Y or N)___________________________________

____________________________Time:______________________

Dinner (Y or N)____

____

____

____________________________Time:______________________

Evening Snack(Y or N):____________________________________

____________________________Time:______________________

Time When You Go To Sleep:_______________

APPENDIX B

Brief Experimental Overview Given to Subjects

24-Hour Sleep Loss Study

As modern technology continues to advance and as industry becomes increasingly reliant upon around-the-clock operations the study of sleep loss has become extremely important. The devastating consequences of sleep loss are evident in many operational settings, for example Three Mile Island nuclear facility in Pennsylvania and Chernobyl nuclear power plant in the Commonwealth of Independent States (formerly the U.S.S.R.), international commercial and military aviation, large-scale emergency medical operations, forest fire fighting, and combat and military operations.

The loss of one night's sleep is an event that occasionally occurs during our busy lives as well. I'm sure you've spent an entire night awake before, for example, studying for a school exam, preparing and writing paper to meet a deadline, driving your car all night long, etc. In this experiment, your performance will be measured several times on a battery of seven laboratory tasks after your normal amount of sleep, and also after one night's sleep loss.

Sleep is a very mysterious necessity in our lives. Some people can effectively and efficiently work after losing their normal amount of sleep. Some people become very tired and are ineffective workers after sleep loss. Most of us would agree that more than one night's sleep loss (e.g. 2, 3 or more night's sleep loss) definitely degrades our ability to perform even simple tasks. However, after one night's sleep loss it is difficult to predict whether or not our performance will be affected.

The goal of this study is to try to carefully study the effects of 24-hour sleep loss. In order to successfully determine these effects, I will need your full cooperation both inside and outside the lab. Your assistance will be a critical and integral aspect of a clean, thorough and scientific analysis of your performance during this week of testing. We ask of you the following things:

(1) Eat and drink your meals and snacks as you would normally do during the week.
(2) Get as much sleep as you would on a normal weekday.
(3) Please fill out the "Food and Sleep Diary" on a daily basis one week prior to the first day of experimental testing.
(4) Please refrain from alcoholic beverages, non-prescription drugs or substances, or excessive amounts of coffee or caffiene-beverages during the week of testing.

Thank you for your participation and full cooperation throughout this experiment. With your support and assistance a better scientific understanding of one night's sleep loss will gained.

APPENDIX C

Experimental Consent Form

INFORMATION PROTECTED BY THE PRIVACY ACT OF 1974

CONSENT FORM

TITLE: Performance, Physiological, and Subjective Effects of One Night's Sleep Deprivation

Work Unit 7184-1425

1. (a) In this experiment, we will measure your performance (e.g. response time and error rates) on a battery of seven standard laboratory tasks.
(b) The purpose of this experiment is to study the performance effects of one night's sleep loss (i.e. 24 hours without sleep) on the battery of laboratory tasks.
(c) Participation in this study consists of a training phase and an experimental phase. The two phases of the experiment will be scheduled for six sessions. The first day will be a training session, and will last approximately 4-5 hours. Experimental sessions will then take place on each of the next 5 days in the morning - requiring approximately 1-2 hours per day.

2. In the first three test sessions, you will be tested under your normal sleep level. The first session will consist of training, and the remainder will be experimental sessions. After the third testing session, you will be asked to spend the entire night at the laboratory. After 24 hours of sleeplessness, you will be tested again, and then on each day following for two more days. During the night of sleep loss, numerous activities will be scheduled to maintain your alertiveness, and investigators will continuously monitor your wakefulness. Water and flavored (however, decaffeinated) beverages and snack food will be provided throughout the sleepless night. You will need to make arrangements for transportation to and from a meeting location, near Wright-Patterson Air Force Base, on the night of sleep loss and the morning after the sleep loss. A completely rested person will meet you at this location; drive you to the on-base testing facilities on the sleep loss night; and drive you to the off-base meeting location on the morning after sleep loss. Since your performance in operating vehicles and machinery (e.g., driving your car) could be impaired, we ask that you refrain from such activities until you have sufficiently recovered. The recommended method of recovery is to simply get your normal amount of sleep as soon as you return home.

In both the training and experimental phases, you will be asked to perform seven simple computer-based tasks, including: (a) reaction test: you will be presented with certain numbers, and you will respond with a button press as quickly as possible to signify your observation of the number; (b) math test: you will be presented with a series of three single-digit addition/subtraction problems, and you will need to solve each problem, determine if it is greater or less than a certain number, and will respond with a button press; (c) memory task: you will memorize a series of letters, and then will be asked if certain letters were or were not in the series you memorized. You will respond with a button press; (d) spatial test: you will view a series of bar graph pairs, and you will respond with a button press as to whether the two graphs were the same or different; (e) tracking task: using a joystick, you will control a cursor moving back and forth on the computer screen; (f) reasoning task: you will be presented with three symbols, and two sentences, both of which either correctly describe the order of the symbols, or one of which incorrectly describes the order. You will respond with a button press; and (g) a combination of the memory and tracking tasks. Actual data will only be collected in the experimental phase.

We are not only interested in assessing your performance but also the experiences you had during the different task conditions. You will be asked to rate each tack condition on set of six scales. These ratings will be used to evaluate your subjective experiences of workload.

During the experimental phase we will also be collecting physiological data. Specifically, we will monitor three channels of EEG, one channel of eyeblink (EOG) activity, and one channel of heart (ECG) activity. To record these data, we will need to apply eight electrodes, three on the scalp for EEG, one behind each ear for signal reference and ground, one above the eye for EOG, one on the sternum and one on the left abdomen for ECG. At each of these electrode sites we will thoroughly clean the area with an alcohol-soaked gauze pad and Omni-Prep solution, and apply the electrodes using small (1/2-inch) adhesive electrode collars. It may be necessary to clip several hairs (1/16-inch diameter) before we can apply the electrodes.

3. You may experience some irritability resulting from the night of sleep loss. This effect is transient and will be resolved by a normal or slightly extended night's sleep the following night.

Data collected in this study will be treated in such a way that will protect your privacy. Data will be published in scientific journals or reports without identifying individual subjects. Results of this study will be available to you upon request.

4. There are no direct, tangible benefits to you for participating in this study. All subjects are paid for participation and are informed of the research objectives. Further, you may contact Dr. Glenn Wilson or Mike Gravelle several months after data collection for a summary of results from this study.

5. No alternative means exist to obtain the information acquired from this experiment. You should incur no personal risk as a result of your participation. You are free to withdraw from the experiment at any time.

6. I, ________________________, am participating because I want to. The decision to participate in this research study is completely voluntary on my part. No one has coerced or intimidated me into participating in this program.

The experimenter has adequately answered any and all questions I have asked about this study, my participation, and the procedures involved, which are set forth above, which I have read. I understand that the principal investigator or his/her designee will be available to answer any questions concerning procedures throughout this study. I understand that if significant new findings develop during the course of this research which may relate to my decision to continue participation, I will be informed. I further understand that I may withdraw this consent at any time and discontinue further participation in this study without prejudice to my entitlements. I also understand that the Medical Consultant for this study may terminate my participation in this study if he/she feels this to be in my best interest. I may be required to undergo certain further examinations, if in the opinion of the Medical Consultant, such examinations are necessary for my health or well-being.

7. I understand that my entitlements to medical care or compensation in the event of injury are governed by federal law and regulation, and that if I desire further information I may contact the Principal Investigator.

8. I understand that for my participation in this project, I shall be entitled to payments as specified in the DOD Pay and Entitlements Manual or in current contracts.

OR

I understand that I will not be paid for my participation in this experiment.

9. I understand that my participation in this study may be photographed, filed, or audio/videotaped. I consent to the use of these media for training purposes and understand that any release of records of my participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 5 U.S.C. 552a, and its implementing regulations. This means personal information will not be released to an unauthorized source without my permission.

10. I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

________________________________ ____________

VOLUNTEER'S SIGNATURE and SSAN DATE

________________________________ ____________

PRINCIPAL'S OR CO-INVESTIGATOR'S SIGNATURE DATE

________________________________ ____________

WITNESS'S SIGNATURE DATE

INFORMATION PROTECTED BY THE PRIVACY ACT OF 1974

Authority 10 U.S.C. 8012, Secretary of the Air Force; powers and duties; delegation by; implemented by DOI 12-1, Office Locator.

Purpose is to request consent for participation in approved medical research studies.

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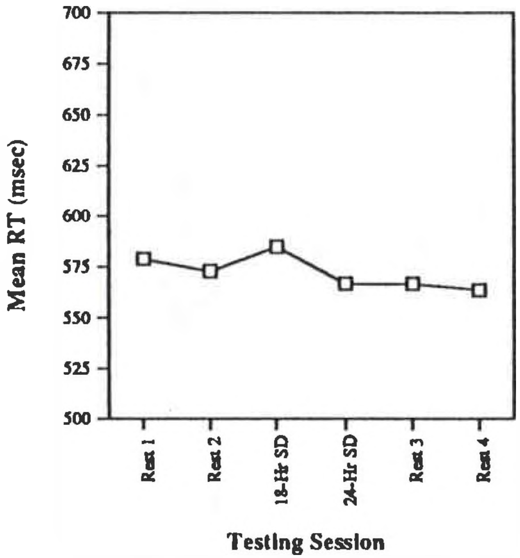
APPENDIX D

Mean RT, Mean SD, and Mean Percent Correct for All Rested Testing Sessions, the Combination of Rested Testing Sessions, and the 18-Hour and 24-Hour Sleep Loss Testing Sessions and Graphs for the Reaction Time Tests

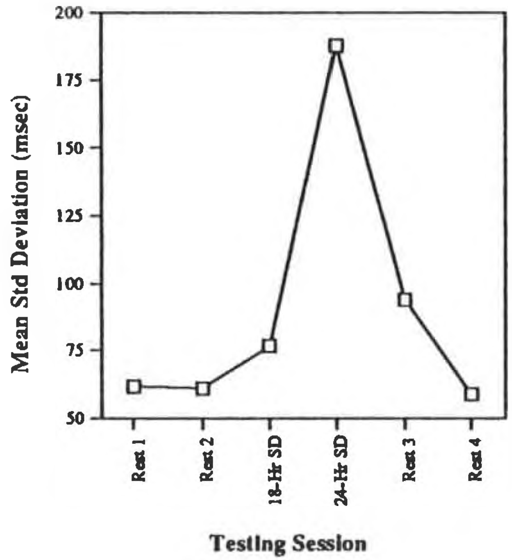
	R1[1]	R2[2]	R3[3]	R4[4]	C-R[5]	18-HR[6]	24-HR[7]
RT							
Basic	578.9	572.3	566.6	563.3	570.3	584.7	566.1
Coded	621.4	609.1	585.5	566.2	595.6	597.0	595.5
Time U	633.0	648.6	611.3	631.9	631.2	651.1	633.8
Double R	997.8	978.2	963.6	963.9	975.9	1007.6	999.4
Inversion	639.7	639.0	624.2	599.7	625.7	658.0	611.5
SD							
Basic	123.7	122.0	123.2	117.0	121.5	153.5	187.9
Coded	150.2	141.0	152.0	159.2	150.6	168.5	208.1
Time U	179.2	141.8	159.8	141.9	155.7	182.9	211.8
Double R	141.8	134.7	-	-	138.3	158.5	237.7
Inversion	197.6	166.2	157.5	169.5	172.7	185.3	209.5
Correct							
Basic	94.7	95.8	94.7	94.4	94.9	90.3	85.0
Coded	91.1	89.7	88.7	88.2	89.4	86.5	79.4
Time U	86.4	89.3	86.8	92.6	88.8	87.2	82.2
Double R	92.1	91.8	91.9	90.9	91.7	88.8	79.4
Inversion	84.8	85.1	81.1	85.5	84.1	80.5	76.0

1 - Rest Day 1
2 - Rest Day 2
3 - Rest Day 3
4 - Rest Day 4
5 - Combination of Rest Days as Prescribed by Cronbach's alpha values
6 - 18-Hour Sleep Loss Session
7 - 24-Hour Sleep Loss Session

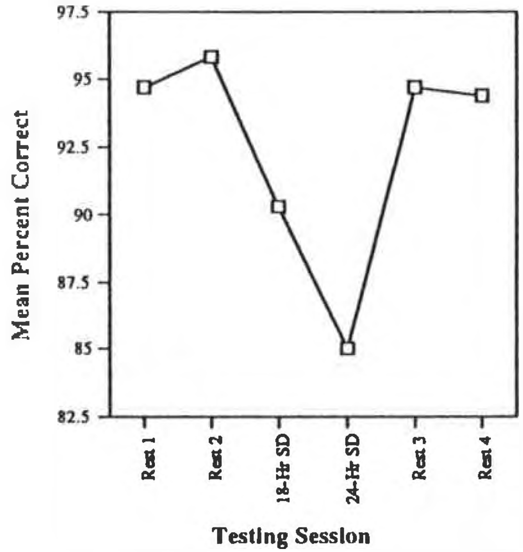
Reaction Time (Basic) - Mean RT



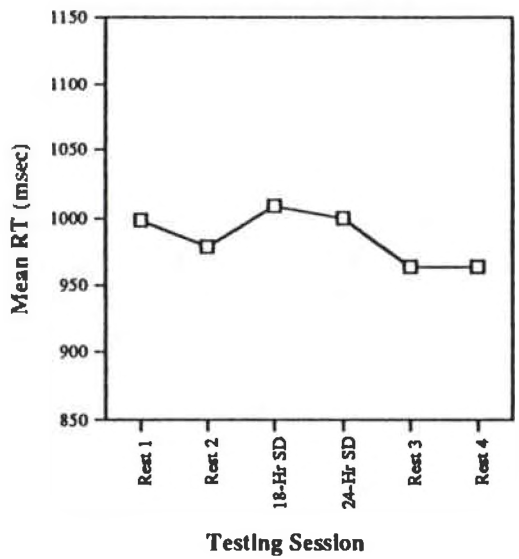
Reaction Time (Basic) - Mean Std Deviation



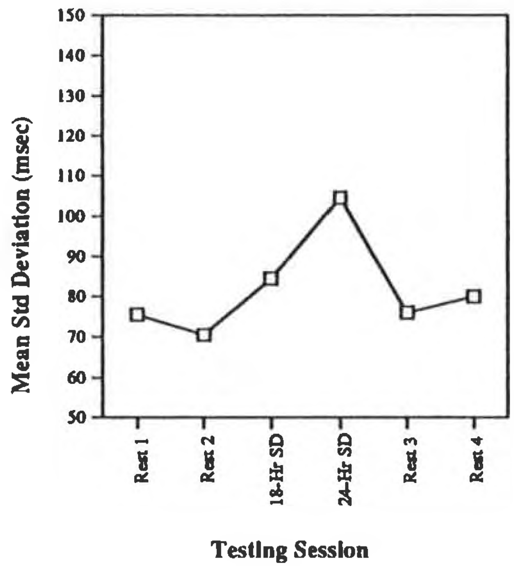
Reaction Time (Basic) - Mean Percent Correct



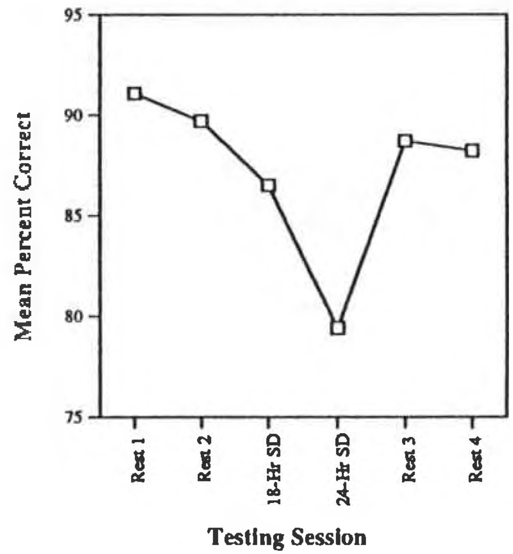
Reaction Time (Double Response) - Mean RT



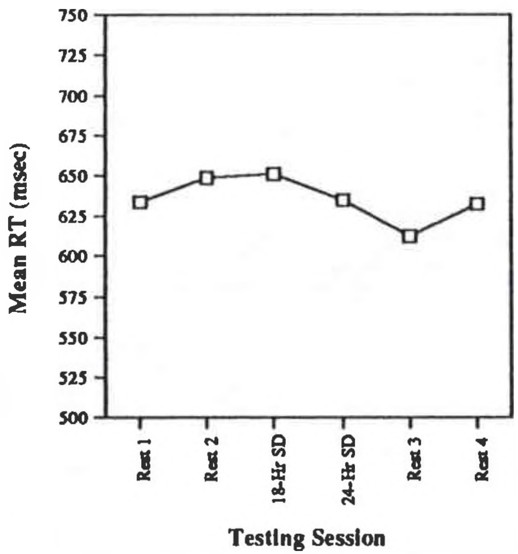
Reaction Time (Coded) - Mean Std Deviation



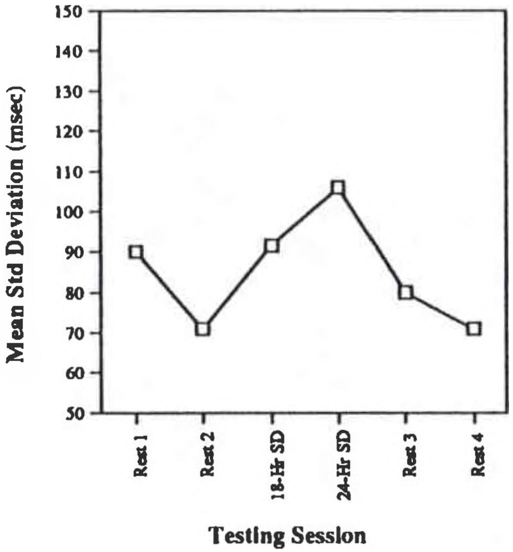
Reaction Time (Coded) - Mean Percent Correct



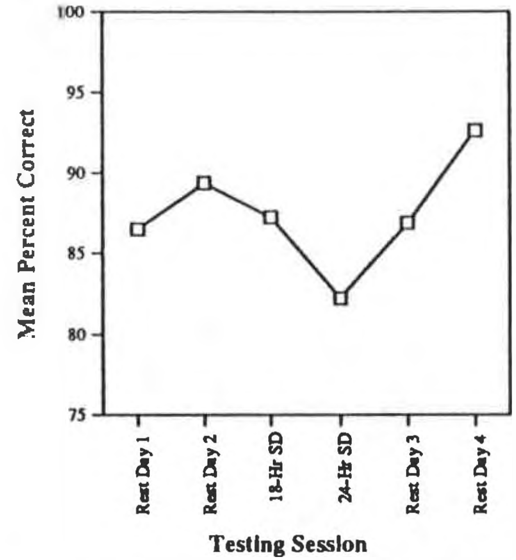
Reaction Time (Time Uncertainty) - Mean RT



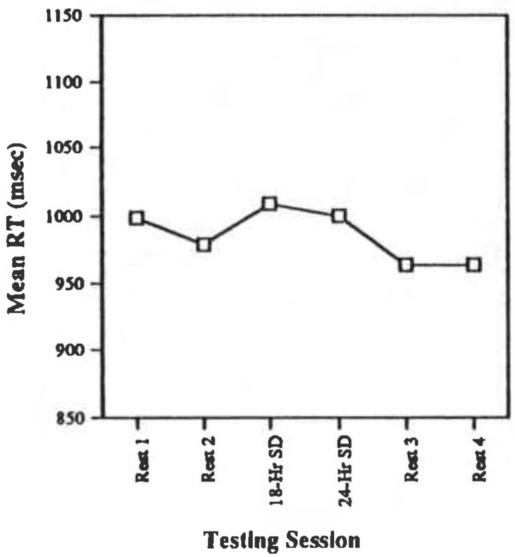
Reaction Time (Time Uncertainty) - Mean Std Deviation



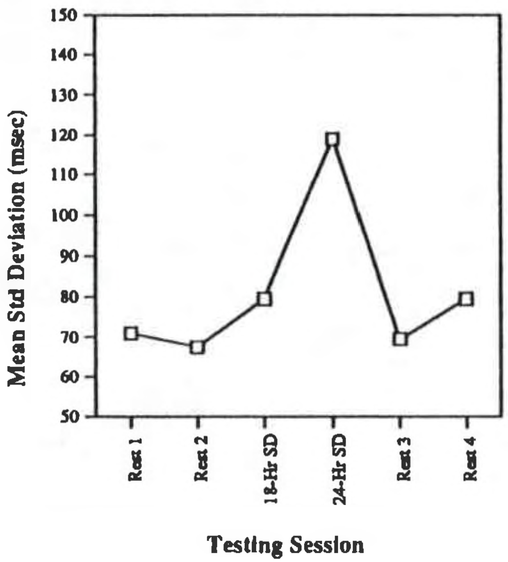
Reaction Time (Time Uncertainty) - Mean Percent Correct



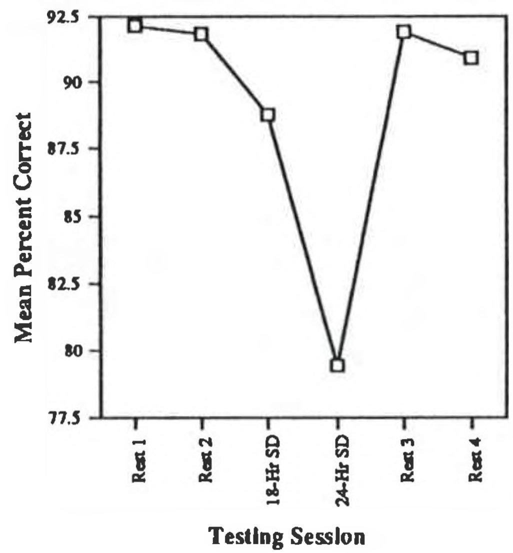
Reaction Time (Double Response) - Mean RT

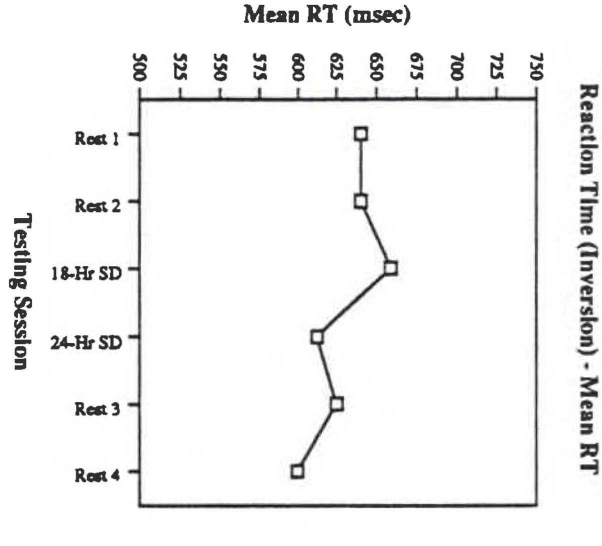


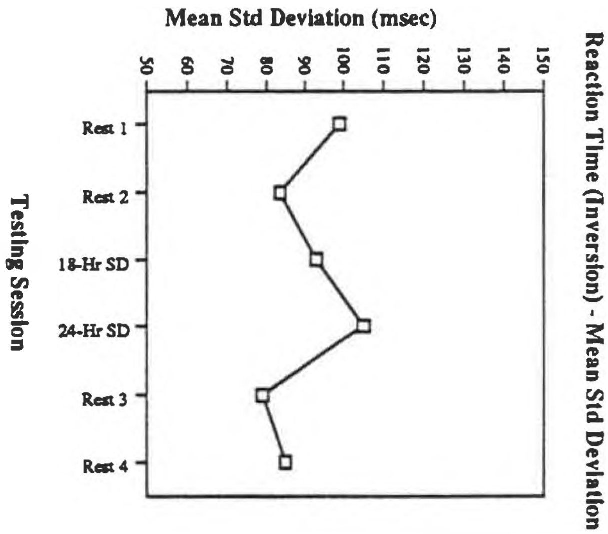
Reaction Time (Double Response) - Mean Std Deviation

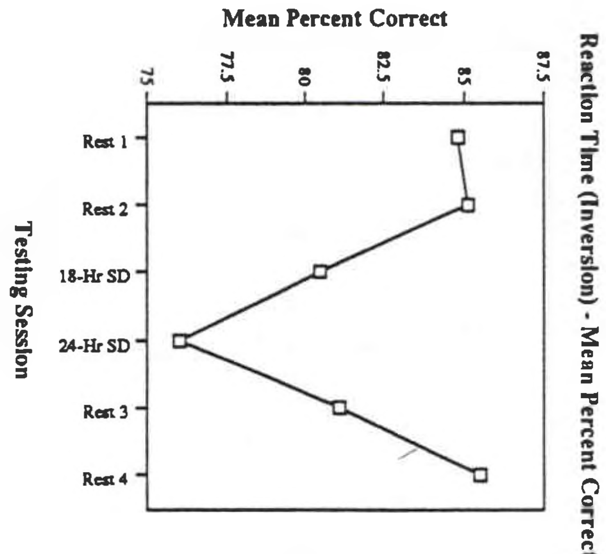


Reaction Time (Double Response) - Mean Percent Correct




Reaction Time (Inversion) - Mean RT
Mean RT (msec)
500
525
550
575
600
625
650
675
700
725
750
Rest 1
Rest 2
18-Hr SD
24-Hr SD
Rest 3
Rest 4
Testing Session


Reaction Time (Inversion) - Mean Std Deviation
Mean Std Deviation (msec)
50
60
70
80
90
100
110
120
130
140
150
Rest 1
Rest 2
18-Hr SD
24-Hr SD
Rest 3
Rest 4
Testing Session


Reaction Time (Inversion) - Mean Percent Correct
Mean Percent Correct
75
77.5
80
82.5
85
87.5
Rest 1
Rest 2
18-Hr SD
24-Hr SD
Rest 3
Rest 4
Testing Session

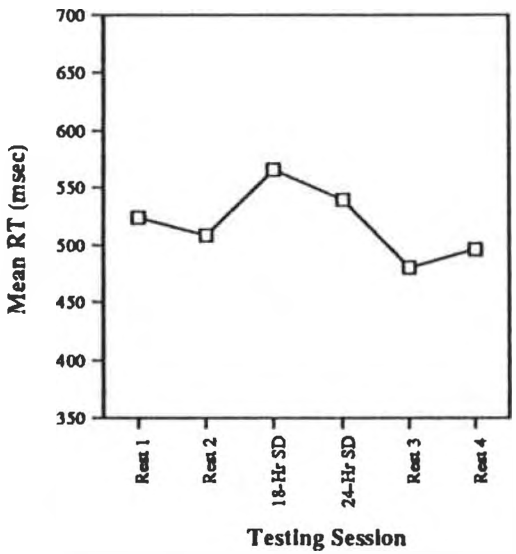
APPENDIX E

Mean RT, Mean SD, and Mean Percent Correct for All Rested Testing Sessions, the Combination of Rested Testing Sessions, and the18-Hour and 24-Hour Sleep Loss Testing Sessions and Graphs for the Memory Search, Mathematical Processing, Spatial Processing, and Grammatical Reasoning Tests

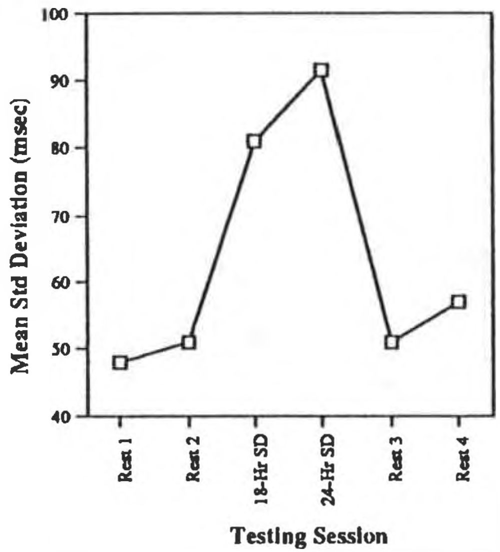
	R1[1]	R2[2]	R3[3]	R4[4]	C-R[5]	18-HR[6]	24-HR[7]
RT							
MS (2)	523.8	509.1	480.7	495.4	502.3	565.5	540.2
MS (4)	571.4	566.3	559.5	572.7	567.5	600.5	599.9
MP	1975.4	1684.9	1532.5	1638.0	1707.7	1824.6	1839.5
SP	1077.3	1112.9	935.1	932.6	1014.5	10005.8	1060.4
GR	5165.5	4664.1	4820.6	4578.1	4807.1	5045.5	5202.0
SD							
MS (2)	95.9	102.0	101.8	113.9	103.4	162.0	182.7
MS (4)	112.1	129.5	136.3	143.1	130.3	160.1	200.3
MP	874.4	603.8	668.2	637.4	696.0	774.6	863.8
SP	323.1	324.0	273.2	290.1	302.6	310.9	381.3
GR	1369.1	1160.6	1291.0	1329.6	1287.6	1334.5	1531.0
Correct							
MS (2)	98.5	97.4	95.7	97.8	97.4	93.8	94.8
MS (4)	99.2	96.7	96.8	95.4	-	94.3	92.5
MP	94.3	91.4	91.9	93.4	92.8	91.2	90.9
SP	92.5	88.4	88.5	93.4	-	88.0	84.7
GR	88.3	92.5	89.5	91.7	-	86.9	89.7

[1] - Rest Day 1
[2] - Rest Day 2
[3] - Rest Day 3
[4] - Rest Day 4
[5] - Combination of Rest Days as Prescribed by Cronbach's alpha values
[6] - 18-Hour Sleep Loss Session
[7] - 24-Hour Sleep Loss Session

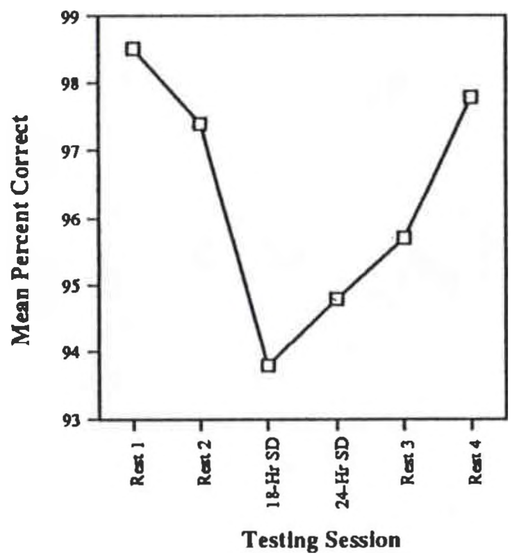
Memory Search (Mset = 2) - Mean RT



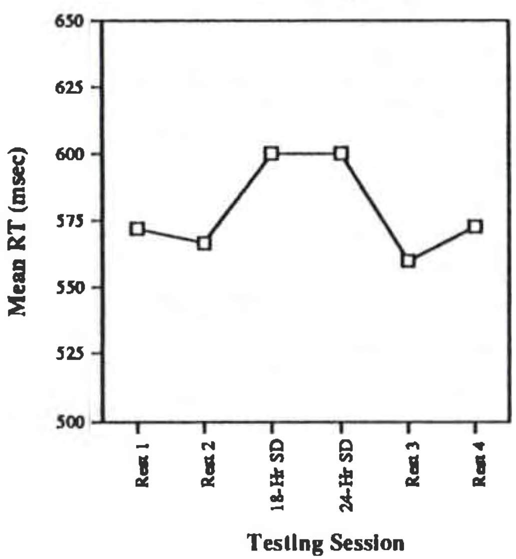
Memory Search (Mset = 2) - Mean Std Deviation



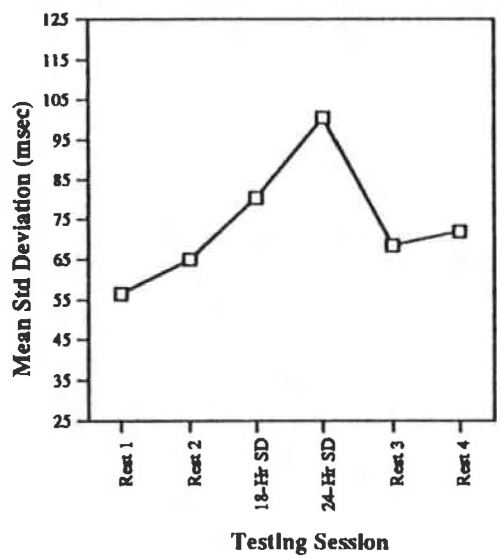
Memory Search (Mset = 2) - Mean Percent Correct



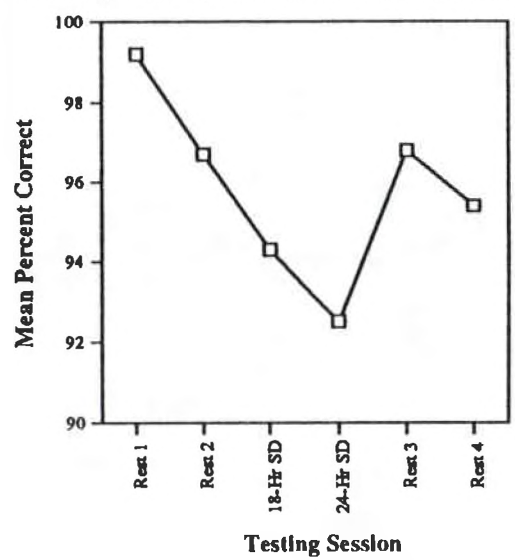
Memory Search (Mset = 4) - Mean RT

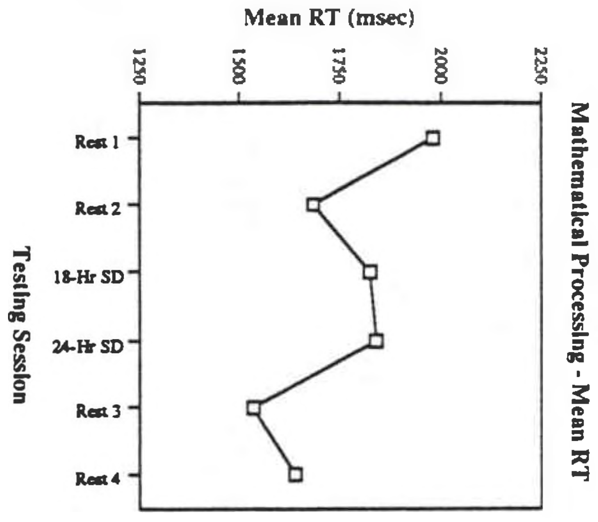


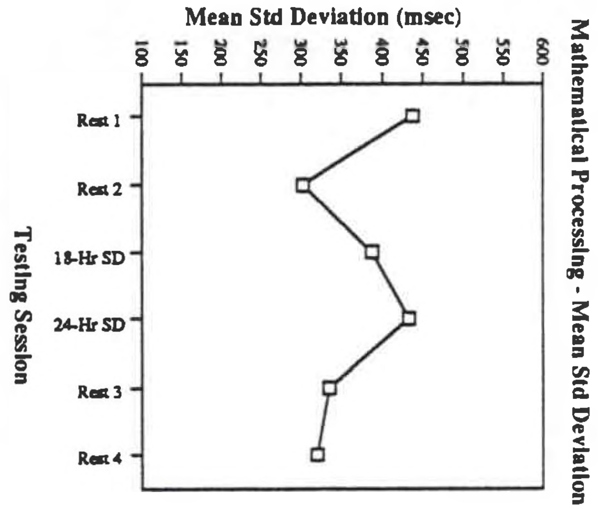
Memory Search (Mset = 4) - Mean Std Deviation

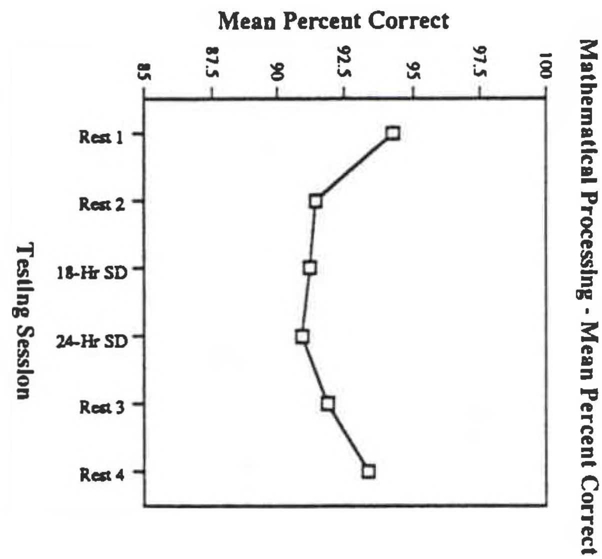


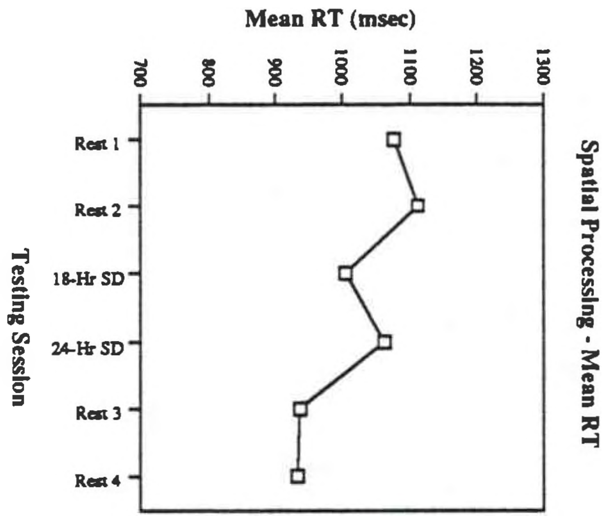
Memory Search (Mset = 4) - Mean Percent Correct

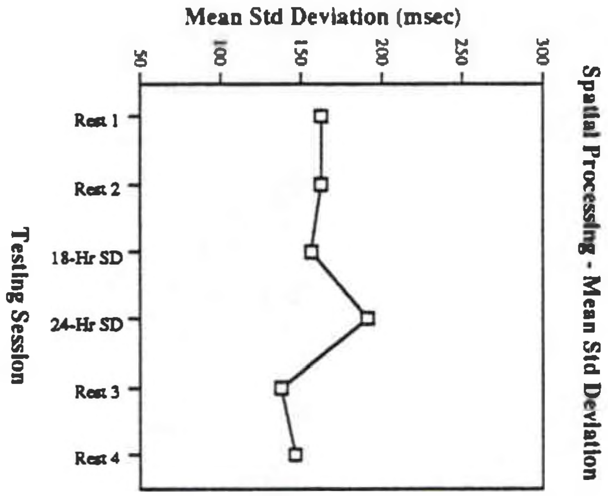


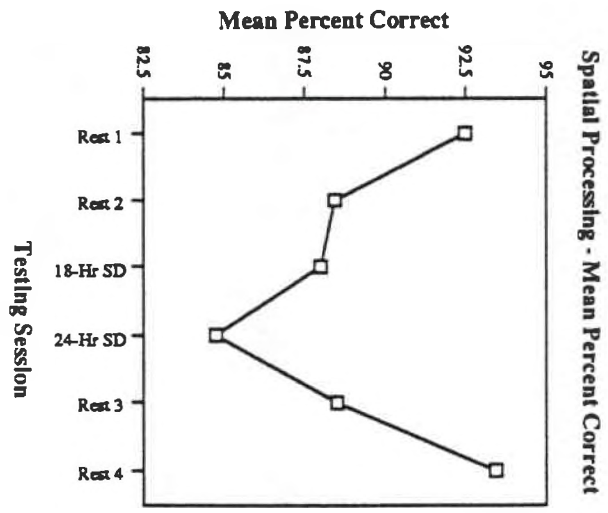

Mathematical Processing - Mean RT
Mean RT (msec)
1250
1500
1750
2000
2250
Rest 1
Rest 2
18-Hr SD
24-Hr SD
Rest 3
Rest 4
Testing Session

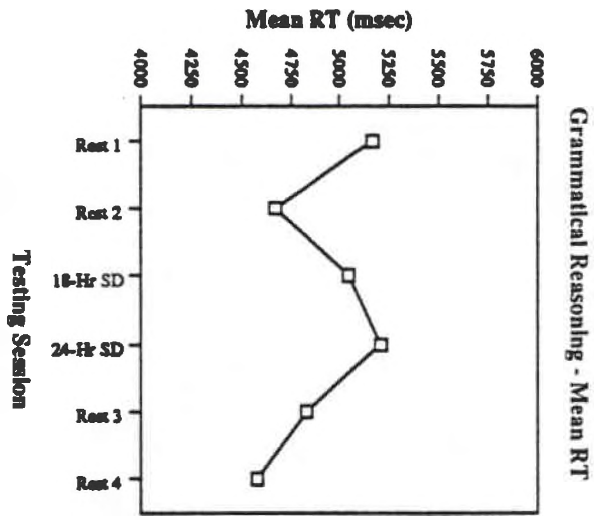

Mathematical Processing - Mean Std Deviation
Mean Std Deviation (msec)
100
150
200
250
300
350
400
450
500
550
600
Rest 1
Rest 2
18-Hr SD
24-Hr SD
Rest 3
Rest 4
Testing Session

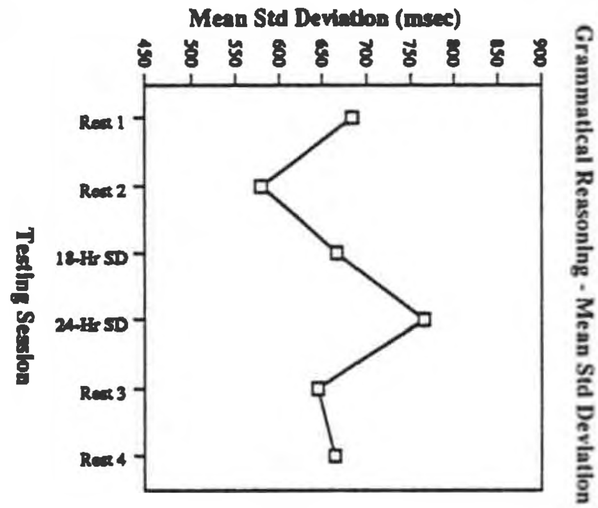

Mathematical Processing - Mean Percent Correct
Mean Percent Correct
85
87.5
90
92.5
95
97.5
100
Rest 1
Rest 2
18-Hr SD
24-Hr SD
Rest 3
Rest 4
Testing Session

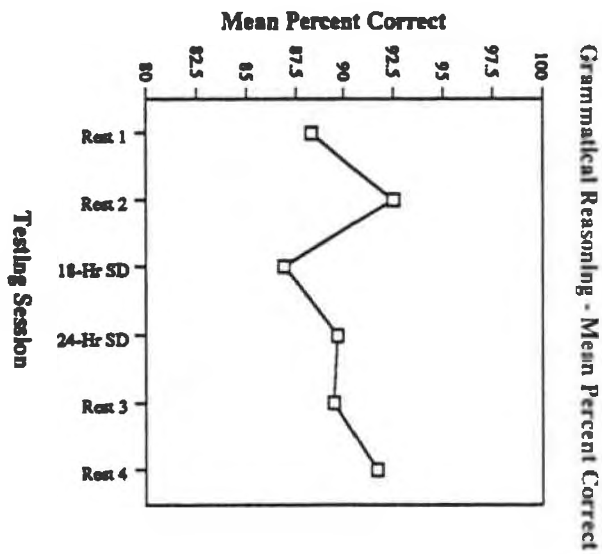

Spatial Processing - Mean RT
Mean RT (msec)
700
800
900
1000
1100
1200
1300
Rest 1
Rest 2
18-Hr SD
24-Hr SD
Rest 3
Rest 4
Testing Session


Spatial Processing - Mean Std Deviation
Mean Std Deviation (msec)
50
100
150
200
250
300
Rest 1
Rest 2
18-Hr SD
24-Hr SD
Rest 3
Rest 4
Testing Session


Spatial Processing - Mean Percent Correct
Mean Percent Correct
82.5
85
87.5
90
92.5
95
Rest 1
Rest 2
18-Hr SD
24-Hr SD
Rest 3
Rest 4
Testing Session


Grammatical Reasoning - Mean RT
Mean RT (msec)
4000
4250
4500
4750
5000
5250
5500
5750
6000
Rest 1
Rest 2
18-Hr SD
24-Hr SD
Rest 3
Rest 4
Testing Session


Grammatical Reasoning - Mean Std Deviation
Mean Std Deviation (msec)
450
500
550
600
650
700
750
800
850
900
Rest 1
Rest 2
18-Hr SD
24-Hr SD
Rest 3
Rest 4
Testing Session


Grammatical Reasoning - Mean Percent Correct
Mean Percent Correct
80
82.5
85
87.5
90
92.5
95
97.5
100
Rest 1
Rest 2
18-Hr SD
24-Hr SD
Rest 3
Rest 4
Testing Session

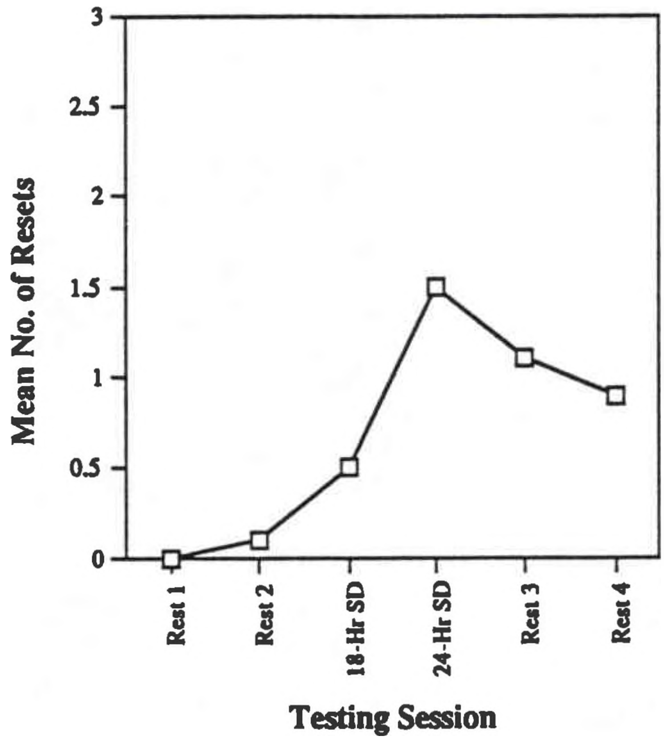
APPENDIX F

Mean RT, Mean SD, and Mean Percent Correct for All Rested Testing Sessions, the Combination of Rested Testing Sessions, and the18-Hour and 24-Hour Sleep Loss Testing Sessions and Graphs for the Unstable Tracking Test

	R1[1]	R2[2]	R3[3]	R4[4]	C-R[5]	18-HR[6]	24-HR[7]
No. of Resets							
U Trkng	0.0	0.1	1.1	0.9	0.5	0.5	1.5
RMS Error							
U Trkng	63.5	52.2	100.0	77.5	73.3	162.6	209.2

1 - Rest Day 1
2 - Rest Day 2
3 - Rest Day 3
4 - Rest Day 4
5 - Combination of Rest Days as Prescribed by Cronbach's alpha values
6 - 18-Hour Sleep Loss Session
7 - 24-Hour Sleep Loss Session

Unstable Tracking - Mean Number of Resets



Unstable Tracking - Mean RMS Error